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Design and test results of AMIGO: A novel remote ground sensor system (U)

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Technical Report
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Abstract

The objectives of the project AMIGO (Autonomous MIcrosystems for Ground Observation) are to explore technologies applicable to unattended ground sensor (UGS) systems and to develop a proof-of-concept, next-generation, low-cost, compact UGS suite that can provide the CF with real-time situational awareness from remote locations. Four prototype AMIGO units were designed, built and tested at DRDC Valcartier. Each AMIGO unit was equipped with passive infrared (PIR) motion sensor, acoustic sensor, uncooled infrared (IR) imager (installed in two of the four), electronic compass, global positioning system (GPS), and spread spectrum wireless transceiver. The physical characteristics of AMIGO are 150 by 85 by 75 mm in size and ~800 grams in weight without batteries. Three types of battery can be used depending on mission life requirement, with battery life between 20 and 333 hours. With the PIR and acoustic sensors, AMIGO can detect a human-size moving target at a maximum standoff distance of 10 m and a vehicle target with engine running at a maximum standoff distance of 20 m. The IR imager allows detection and recognition of vehicle targets at 300 m and 165 m, and for human targets, at 220 m and 135 m, respectively. The AMIGO unit was configured for multipoint-to-point communication (several AMIGO units to one base station). IR images and other information are transmitted wirelessly to the base station upon triggering by PIR or acoustic sensor. The range of the reliable wireless link is between 150 m and 1.2 km depending on sensor location, communication line of sight and terrain altitude. In addition, field trials were conducted with AMIGO in various scenarios. These scenarios include personnel and vehicle intrusion detection (by motion or sound) and target imaging, determination of target GPS position by triangulation, real-time GPS tracking, entrance event counting, indoor surveillance, and aerial surveillance on a radio-controlled model plane. In these trials AMIGO performed effectively and detected targets according to the specifications. The results showed that this prototype could be used on basic surveillance missions.

Résumé

Le projet AMIGO (Autonomous MIcrosystems for Ground Observation) a pour but d'étudier les technologies relatives aux systèmes de détecteurs autonomes au sol (DAS) et de mettre au point, puis de valider une nouvelle génération de DAS compacts de faible coût afin de doter les FC d'une capacité de connaissance de la situation à distance et en temps réel. On a conçu, fabriqué et expérimenté quatre prototypes d'AMIGO à RDDC Valcartier. Chaque système AMIGO était équipé de détecteurs infrarouges passifs de mouvement, de détecteurs acoustiques, d'imageurs infrarouges (IR) non refroidis (deux détecteurs), d'une boussole électronique, d'un système de positionnement global (GPS) et d'un émetteur-récepteur sans fil à étalement du spectre. Les dimensions d'AMIGO sont de 150 mm sur 85 mm sur 75 mm et son poids est d'environ 800 grammes sans les piles. On peut utiliser trois types de piles, selon la durée de la mission, pour une autonomie variant entre 20 et 333 heures. Équipé de capteurs IR passifs et acoustiques, AMIGO peut détecter une cible en mouvement de dimension humaine à une distance maximale de 10 m et un véhicule en marche à une distance maximale de 20 m. L'imageur infrarouge permet la détection et la reconnaissance de véhicules à 300 m et à 165 m respectivement, et de cibles humaines à 220 m et à 135 m respectivement. La configuration d'AMIGO permet un mode de communication multipoint (systèmes AMIGO) à point (station de base). Les images IR et toutes les autres données sont transmises par réseau sans fil à la station de base et la mise en circuit s'effectue au moyen de capteurs IR passifs et acoustiques. La distance fiable de communication sans fil se situe entre 150 m et 1,2 km, selon l'emplacement du capteur, la portée optique et la disposition du terrain. Par ailleurs, on a testé AMIGO sur le terrain selon divers scénarios. Parmi ceux-ci, notons la détection d'intrusion par une personne ou un véhicule (mouvement ou son) et l'imagerie des cibles; la localisation de cibles par triangulation; la poursuite de position GPS en temps réel; le décompte des entrées; la surveillance intérieure; et la surveillance aérienne par modèle radioguidé. Au cours de ces essais, AMIGO fonctionnait normalement et pouvait détecter les cibles selon les paramètres établis. Les résultats démontrent que le prototype pourrait être utilisé lors de missions de surveillance de routine.

Executive summary

Military forces need to collect field information for surveillance and operations planning purposes. These operations are carried out by personnel or by air surveillance with expensive, sophisticated sensors. But monitoring operations are hard to sustain in volatile situations and the cost of continuous surveillance is high. Deployments are risky and take considerable time to prepare, coordinate and execute. Therefore, there is a need to develop low-cost sensors to collect and report field information to base autonomously. This is the motivation behind the concept of the project AMIGO (Autonomous MIcrosystems for Ground Observation) currently under investigation at DRDC Valcartier.

The objectives of project AMIGO are to study various sensing technologies with potential for unattended ground sensor (UGS) applications and to develop a proof-of-concept, next-generation, low-cost, compact UGS suite that can provide the CF with real-time situational awareness from remote locations. Four prototype AMIGO units were designed, built and tested at DRDC Valcartier. Each AMIGO unit was equipped with passive infrared (PIR) motion sensor, acoustic sensor, electronic compass, global positioning system (GPS) and spread spectrum wireless transceiver. Uncooled infrared (IR) imagers also were installed in two of the four units. A PC laptop base station was used to monitor and control all AMIGO units through a graphic user interface program.

The physical specifications of AMIGO are 150 by 85 by 75 mm in size and ~800 grams in weight without batteries. Three types of batteries can be used depending on mission life requirement, with battery life varying between 20 and 333 hours. Operational performance was evaluated. With the PIR and acoustic sensors, AMIGO could detect a human-size moving target at a maximum standoff distance of 10 m, and a vehicle target with engine running at a maximum standoff distance of 20 m. The current IR imager allows detection and recognition of vehicle targets at 300 m and 165 m, and for human targets, at 220 m and 135 m, respectively. The AMIGO unit was configured for multipoint-to-point communication (several AMIGO units to one base station). IR images and other information are transmitted wirelessly to the base station upon triggering by PIR or acoustic sensor. The range of the reliable wireless link is between 150 m and 1.2 km depending on sensor location, communication line of sight and terrain altitude.

Field trials were conducted with AMIGO in various scenarios. These scenarios include personnel and vehicle intrusion detection (by motion or sound) and target imaging, determination of target GPS position by triangulation, real-time GPS tracking, entrance event counting, indoor surveillance, and aerial surveillance on a radio-controlled model plane. In these trials AMIGO performed effectively and detected targets according to the specifications. The results showed that this prototype could be used on basic surveillance missions. Future trials with the CF are being scheduled.

In comparison with commercial UGSs on the market, the AMIGO prototype system is excellent in terms of weight, size and overall capabilities. Many specifications conform to NATO remote ground sensor system requirements (dated March 2005). In subsequent UGS research and development, a modular approach will be considered instead of the current “all-

in-a-box" design. In this modular design, the unit will be designed in three main "LEGO-type" modules: imager (expensive IR or low-cost visible), main body with basic low-cost sensors and electronics, and mobile platform. As a result, the sensor capabilities can be tailored to mission requirements. Moreover, a reliable wireless network is indispensable. This challenge is heightened by the limitation of radio transmission power available at each node for acceptable mission life and sensor weight. Since it is impossible to accurately predict the effects of terrain, weather and surrounding structures on wireless communications in the area of operation, a smarter network is desirable. The advanced development of ad-hoc networking will produce a more versatile multi-node wireless network.

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Sommaire

De nos jours, les activités militaires nécessitent de recueillir des renseignements sur le terrain à des fins de surveillance or de préparation. À l’heure actuelle, ces opérations sont effectuées par le personnel ou par surveillance aérienne au moyen de capteurs de pointe à coût élevé. Cette surveillance est difficile à assurer dans des conditions changeantes et le coût d’une surveillance constante est élevé. Non seulement le déploiement peut se révéler risqué, mais il nécessite du temps de préparation et de coordination. Il est donc nécessaire de mettre au point des capteurs de faible coût afin de recueillir et de transmettre l’information sur le terrain à la base de façon autonome. C’est ce qui a mené à l’élaboration du concept du projet AMIGO (Autonomous MIcrosystems for Ground Observation), actuellement à l’étude à RDDC Valcartier.

Le projet AMIGO a pour but d’étudier diverses technologies de détection relatives aux systèmes de détecteurs autonomes au sol (DAS) et de mettre au point, puis de valider une nouvelle génération de DAS compacts de faible coût afin de doter les FC d’une capacité de connaissance de la situation à distance et en temps réel. On a conçu, fabriqué et expérimenté quatre prototypes AMIGO à RDDC Valcartier. Chaque système AMIGO était équipé de détecteurs infrarouges passifs de mouvement, de détecteurs acoustiques, d’une boussole électronique, d’un système de positionnement global (GPS) et d’un émetteur-récepteur sans fil à étalement du spectre. Deux des quatre systèmes étaient équipés d’imageurs infrarouges (IR) non refroidis. La surveillance des systèmes AMIGO était assurée au moyen d’une interface graphique à partir d’un poste de travail.

Les dimensions d’AMIGO sont de 150 mm sur 85 mm sur 75 mm et son poids est d’environ 800 grammes sans les piles. On peut utiliser trois types de piles selon la durée de la mission, pour une autonomie variant entre 20 et 333 heures. On a testé la performance opérationnelle du système. Équipé de capteurs IR passifs et acoustiques, AMIGO peut détecter une cible en mouvement de dimension humaine à une distance maximale de 10 m et un véhicule en marche à une distance maximale de 20 m. L’imageur infrarouge permet la détection et la reconnaissance de véhicules à 300 m et à 165 m respectivement, et de cibles humaines à 220 m et à 135 m respectivement. La configuration d’AMIGO permet un mode de communication multipoint (systèmes AMIGO) à point (station de base). Les images IR et toutes les autres données sont transmises par réseau sans fil à la station de base et la mise en circuit s’effectue au moyen de capteurs IR passifs et acoustiques. La distance fiable de communication sans fil se situe entre 150 m et 1,2 km, selon l’emplacement du capteur, la portée optique et la disposition du terrain

Par ailleurs, on a testé AMIGO sur le terrain à RDDC Valcartier selon divers scénarios. Parmi ceux-ci, notons la détection d’intrusion par une personne ou un véhicule (mouvement ou son) et l’imagerie des cibles; la localisation de cibles par triangulation; la poursuite de position GPS en temps réel; le décompte des entrées; et la surveillance intérieure; la surveillance aérienne par modèle radioguidé. Au cours de ces essais, AMIGO fonctionnait normalement et pouvait détecter les cibles selon les paramètres établis. Les résultats démontrent que le prototype pourrait être utilisé lors de missions de surveillance de routine. On a prévu des essais avec les FC.

En comparaison des DAS qu’on trouve sur le marché, la performance générale du prototype AMIGO est excellente du point de vue du poids, des dimensions et des capacités. De nombreuses caractéristiques sont conformes aux exigences de l’OTAN concernant les capteurs au sol éloignés (mars 2005). Dans la R et D sur les DAS, on examinera la méthode des modules plutôt que la méthode habituelle du tout en un. Selon cette structure modulaire, le système est divisé en trois modules principaux : l’imageur (dispositif à couplage de charge dans le visible à faible prix ou dans l’IR à prix élevé); le corps principal équipé de capteurs et de composants électroniques de base à faible prix; et une plate-forme mobile. On peut ainsi adapter les capacités des capteurs aux exigences de la mission. Par ailleurs, un réseau sans fil fiable est nécessaire. Il faut notamment tenir compte des besoins de puissance d’émission nécessaire à chaque nœud pour répondre aux exigences de durée de mission et de poids de capteur. Comme on n’est pas en mesure de déterminer précisément à l’avance les effets du terrain, de la température qu’il fait et des infrastructures environnantes sur la communication sans fil dans le secteur d’opération, un réseau plus intelligent est souhaitable. L’élaboration d’une mise en réseau qui s’adapte aux circonstances permettra la création d’un réseau sans fil multinodal plus polyvalent.

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Introduction

In today's military operations, there is a need to perform surveillance and collect field information for situational awareness purposes. These functions are now carried out by deploying personnel and expensive, sophisticated platforms. It is clear that these monitoring systems are hard to maintain in volatile situations, and the cost of continuous surveillance is high. In addition, such deployments are risky, particularly for personnel. In order to mitigate mission risks and increase surveillance capability, research and development programs were initiated to explore the use of unattended ground sensors (UGSs) or remote ground sensors (RGSs). There has been some success in UGS development leading to commercial products and subsequent sensor deployments in military operations as far back as the Vietnam War. Although many of the commercial and proof-of-concept UGS systems to date are quite capable, many suffer from one or more of the following drawbacks: information ambiguity, large size and weight for portability, and high sensor cost making mass deployment unfeasible. Therefore, there is a need to develop low-cost (mass deployment), low-power consumption (extended mission life), and miniature (hand-portability) sensors which can be deployed in large quantity to cover a wide area and can routinely collect and report field information to command posts and personnel. This is the motivation behind the Autonomous MIcrosystems for Ground Observation (AMIGO) project currently being investigated at DRDC Valcartier. The aim of the project is to study surveillance technologies applicable to UGS systems, to establish a preliminary standard, to design and construct prototype microsystems, and to identify strategies and directions for further improvement of the sensor systems.

AMIGO is intended for use in open terrain or urban areas to locate, count and classify time-critical targets. It consists of a number of AMIGO units that gather, store and transmit time-critical images from a remote location to a computer or base station via wireless RF link. It is obvious that reliable two-way wireless transmission must be maintained at all times between the base station and each remote unit. Tests were conducted to evaluate wireless performance and the results were reported in a DRDC Technical Note [1]. For further technical information on the synchronization mechanisms (radio and protocol) of the wireless transceiver, please refer to the transceiver technical manual [2].

In the first part of this technical report, a brief background on UGS systems and sensor technologies is presented. This is followed by the design and operational concept of AMIGO. The hardware is described in detail, followed by the final schematic, block diagram and printed circuit board (PCB) of the system. A description of the firmware programming will be given as well. Next, a description of the graphic user interface (GUI) and different aspects of the programming is presented. Once constructed, AMIGO was subjected to preliminary trials. Simulated surveillance operations using AMIGO are described. These include personnel and vehicle proximity (motion or sound) detection and target image acquisition, multiple target imaging for GPS position estimation, entrance event counting, indoor surveillance, real-time GPS position tracking, and aerial surveillance using a radio-controlled model plane. All tests were performed in line-of-sight (LOS), partial LOS and non-LOS (NLOS) settings. All tests were carried out during daytime. The test results are presented. Finally, a discussion of current and future UGS technologies, the specifications for the prototype system produced, and proposals for future work are presented.

Under the supervision of the scientific authority, an electrical engineering consultant designed and completed the majority of the hardware-related tasks (hardware and firmware), while a software engineering consultant designed and implemented the GUI (software). All the work was conducted on site with the assistance of the personnel and facilities of DRDC Valcartier.

The work was supported under Work Breakdown Element 12pa12 (was 12kc12) entitled “Autonomous Micro Sensors”. This report summarizes the work performed on the project at DRDC Valcartier between March 2001 and September 2004.

Background – UGS systems and sensors

This section presents an overview of UGS systems from the first to the current generation and the technologies of some commonly used UGS sensors.

UGS systems

One of the first UGS initiatives was the REMBASS (Remotely Monitored Battlefield Sensor System) developed by the Combat Surveillance and Target Acquisition (CSTA) Laboratory in the US. Acoustic, seismic, magnetic and (non-imaging) IR sensors were integrated together to detect and track Vietcong movements during the Vietnam War. The Improved REMBASS2 [3] or I-REMBASS maintains all of its predecessor's capabilities with reduced size (<200 cm^3), reduced weight (<2 kg), and enhanced component integration and processing functions. Both REMBASS and I-REMBASS are passive systems and employ typical UGS operation mode. They contain sensors that, once in place, can be left unattended for up to 30 days. The sensors are normally in idle mode with very low power dissipation. When a target comes into detection range, the sensors note a change in the ambient energy level (seismic/acoustic, thermal disturbance due to target motion, and/or magnetic), and are activated. The sensors classify the target (as a person or a tracked or wheeled vehicle), format this information into short digital messages, and transmit the messages to a monitoring device. Information received at the monitoring device is decoded and displayed, showing target classification and direction of travel.

Other UGS developers used similar concepts, such as the 20 plus-year-old Classic 2000 from Thales UK, the Mini Intrusion Detection System (MIDS) developed by Sandia National Laboratory, and the INtrusion-tolerant SEnsor NetworkS (INSENS) from Lawrence Livermore National Laboratory. Since target motion, sound, vibration and proximity of metal object phenomenologies are used to determine the nature and class of targets, information ambiguity could not be eliminated completely for major decisions (e.g. weapon effect delivery). Besides providing less confident circumstantial information, many of these UGS systems have a simple communication protocol and minimal or no network capability. For example, each Classic 2000 UGS communicates with the base station but there is no send/acknowledge or handshake protocol to prevent communication loss when two or more UGSs are sending an alarm to the base at the same time. In addition, sensors do not have access to information from other sensors, whether through the base station or directly from the other sensor. To reduce ambiguity, imagers have been recently integrated into UGS systems such as the Terrain Commander from Textron Systems US. Equipped with an IR imager, the new Terrain Commander provides day and night imaging for high-fidelity target recognition and identification. However, the weight of the unit (11 kg base station and 6 kg camera unit and system) makes it less portable and hard to deploy. As a result, the evolution of UGS technologies continues to pursue more compact, capable and versatile surveillance systems.

UGS sensors

A UGS system consists of various types of sensors. Currently used UGS systems are operated with one or more types of sensors and RF communication electronics. The following are some typical sensors used in UGS systems.

Seismic sensor – The sensor detects ground vibration caused by footsteps or moving vehicles. The sensor is not very large and is buried just below the surface of the ground. It is powered by batteries. The nominal range is 300 m for vehicles and 30 m for personnel. The range depends on soil dryness where dry ground results in shorter range than wet ground. An array can be used to determine direction of arrival (DOA) and classify moving targets.

Acoustic sensor – The sensor collects sounds present in the area. The usable frequency range for signal processing of ground vehicles is limited approximately to the range of 20 to 200 Hz for the detection range of interest (dominated below 20 Hz by wind noise and dominated above 200 Hz by poor propagation characteristics). The range depends largely on environmental conditions such as humidity, ambient temperature and temperature gradient vs altitude, wind speed and direction, and terrain condition (roughness). For example, the range on a hot sunny day is shorter than on a clear sky night. An array can be used to determine DOA and classify moving targets down to the number of cylinders.

Magnetic sensor – Magnetic sensors detect the metallic mass associated with vehicles and weapons. Magnetic sensors are unaffected by background activity and weather. The strength of a magnetic field is a function of both target mass and range. This sensor can detect personnel carrying ferrous metal (e.g. rifle) at a range of three to four metres and a 2.5 ton truck at 15 to 20 m. A single sensor cannot distinguish between an infiltrator at close range and a vehicle at long range. By combining magnetic sensors with acoustic and/or seismic sensors, one can increase the target identification probability, e.g. a magnetic signature plus a seismic one means that it is probably a vehicle.

Passive infrared (PIR) detector – The common PIR detector consists of a dual IR sensing element that senses the change of temperature in the FOV. A segmented mirror or fresnel lens is added to create discrete spatial zones covering the FOV. As a result, a person entering the FOV will pass through the zones causing a temperature change for PIR detection. The dual configuration is for differential operation that compensates for the effects of wind, warm air, daylight and other stimuli on the detector, dramatically reducing false alarms. With the use of a second PIR detector (two beams), the DOA can be determined. Depending on the sensor configuration, the nominal detection range of a PIR detector is between a few metres and 100 m. The range can be varied with the field of view and the number of elements in the array. The sensor can be tuned to reduce false alarms resulting from natural activity.

For all these sensors, accurate target identification can be achieved when they are deployed in groups. For example, the mass of an object may be estimated using seismic sensors by noting which UGS units are activated; or, in the case of magnetic sensors, a large object can activate several simultaneously while a person with a weapon would only activate one. A moving object would activate sensors sequentially, so that the direction and speed of movement through the sensor array can be estimated.

Other sensors like fence-type sensors, break-wire detectors, and chemical and biological sensors will not be considered in this project. Table 1 summarizes the characteristics of magnetic, acoustic and seismic sensors and their detection and classification performance on vehicle target [4].

Table 1. Different sensor characteristics and performance with the use of multiple sensor types on vehicle target

	FEATURE	MEASUREMENT	ERROR	SAMPLING	DETECT/CLASSIFY RANGE
Magnetic	Speed	0-100 km/h	+/- 15%	1 s	200 m / 100 m
	Heading	+/- degrees	+/- 15 degrees	1 s	
	Range	10-100 m	-	1 s	
	Height	1-10 m	-	1 s	
	Dipole class	Hvy/light-wheel/track	Prob. correct: .8	1 s	
Seismic	Azimuth	+/- degrees	+/- 45 degrees	10 s	10 m – 4 km /
	Target type	Heavy/light	Prob. correct: .55	10 s	10 m – 1 km
	Tread type	Wheeled/track	Prob. correct: .55	10 s	
	Engine type	Gas/diesel/turbine	Prob. correct: .55	10 s	
	Trans. type	Auto/manual	Prob. correct: .55	10 s	
	# of cylinders	2-12	Prob. correct: .5	10 s	
	Vehicle wgt.	X kg	-	10 s	
Acoustic	Azimuth	+/- degrees	+/- 5 degrees	1 s	2–3 km/500 m
	Target type	Heavy/light	Prob. correct: .6	1 s	
	Tread type	Wheeled/track	Prob. correct: .6	1 s	
	Engine type	Gas/diesel/turbine	Prob. correct: .6	1 s	
	Trans. type	Auto/manual	Prob. correct: .55	1 s	
	# of cylinders	2-12	Prob. correct: .5	1 s	
	RPM	400-10000	Std. dev. 2–5 Hz	1 s	

Design concept and operation of AMIGO

As sensor technologies and electronics continue to evolve, it is becoming possible to integrate novel sensors and electronics with UGS systems that are still low-cost for massive deployment over an area of operation (AO). In this project, new UGS technologies along with proven technologies were selected and tested for new operation concepts.

The basic sensor system can be broken down into four parts: (i) major hardware (excluding RF transceiver), including sensors, electronics, batteries, hardware programming, and user interface programming for command and control; (ii) data processing algorithms; (iii) wireless transmission, including RF transceiver, communication protocols, networking and data compression; and (iv) data/information management, organization and presentation on a user interface. In this work, the emphasis is on the first major hardware. Sensor selections were based on required sensing phenomenon and on component performance, size, weight, robustness and power consumption.

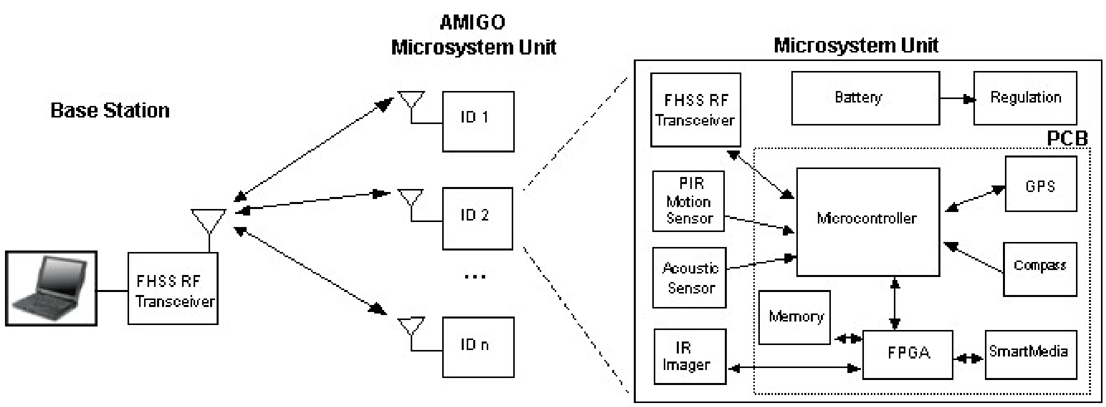


Figure 1. Architecture of AMIGO system

The architecture of AMIGO is depicted in Figure 1. The AMIGO system consists of a base station and one or more hand-placed microsystem units containing a passive infrared (PIR) motion sensor, acoustic sensor and uncooled infrared (IR) imager. Unlike its counterpart photonic IR imager, an uncooled IR imager does not require cryogenic cooling. This imager is compact, lightweight and low-cost. With a modest sensitivity, this imager provides day and night imaging capability.

There are two versions of AMIGO: with and without IR imager. While on standby to conserve energy, AMIGO is triggered into action by either PIR or acoustic sensors in case of proximity detection. Upon triggering, an AMIGO with IR imager will immediately take and send images to a command post, providing almost real-time situational awareness. IR imaging provides around-the-clock, highly confident information enabling target confirmation before troop commitment. In a different configuration, many AMIGO units without IR imager can be deployed over a large area. They can be set to trigger an AMIGO with IR imager located at a strategic position (such as a rooftop) to provide wider coverage. Additional target information is provided by a GPS module and electronic compass installed in each AMIGO. In the case of on-going sensor deployment, redeployment or an AMIGO mounted on a mobile platform, one can acquire the updated position and heading of AMIGO and perform AMIGO position tracking and target triangulation. A custom-written program stored in the AMIGO flash memory governs all AMIGO operations. The status and acquired images can be transmitted through the RF transceiver of AMIGO. A base station can be established with a graphic user interface (GUI) showing all the gathered information overlaid on a geo-referenced, digitized map or aerial image for enhanced visualization.

The operation of AMIGO is intended to provide short-range LOS and non-LOS surveillance to complement long-range LOS surveillance, and to provide continuous monitoring of gaps up to 1 km^2 between sub-units, roads, and key terrain within a unit AO around-the-clock and in reduced visibility due to adverse weather conditions and obscuration. Commanders maintain remote observation over the sensors and terrain via the GUI at the base station.

Hardware

In this section a detailed description of the AMIGO hardware is presented. Component selection was based on functionality and performance, power consumption, size, weight and cost. It is noted that best efforts were made to respect these rules. The components include CPU, memory, complex programmable logic device (CPLD), SmartMedia card reader, electronic compass, GPS module, and passive infrared (PIR) motion and acoustic sensors. Most of the components were populated onto a custom-designed printed circuit board (PCB). Other components and sub-circuits that were connected to the main PCB include DC/DC converter, acoustic sensor with audio trigger board, uncooled IR imager with video digitizing board, RF transceiver and GPS antenna. An external connector was added to the PCB to drive a future motor circuit for unit movement.

Central processing unit

An 8-bit AVR Atmega103L microcontroller from Atmel was selected as the CPU in each AMIGO unit. This low-power, low-cost CPU can run at 4 MHz at 3.3 V and its reduced instruction set computing (RISC) architecture provides 1 MIPS/MHz. It consumes 18 mW, 5 mW, and 3 μW at 3.3 V in active mode, idle, and power down mode, respectively. Major features are the 128 Kbytes In-System programmable flash memory, 4 Kbytes internal EEPROM, and 4 Kbytes SRAM. The microcontroller is packaged in a small 64-pin package. It has two serial ports: a Serial Protocol Interface (SPI), and a Universal Synchronous/Asynchronous Receiver/Transmitter (USART) for RS232 communications. The chip has one UART available that is multiplexed between the GPS second serial port and the camera serial port. Two more serial ports were implemented using an external dual UART chip connected to the RF transceiver and the GPS primary serial port. This CPU is not capable of handling large volumes of data for images and sound processing. On the other hand, it is adequate for handling low volumes of data and communication with the base station.

Memory and SmartMedia™ interfaces

In AMIGO, memory modules were used to store acquired images and other data such as device settings and programs. Toshiba TC554001 memory modules were selected. Each module is a static random access memory (SRAM) with 512 Kbytes storage capacity in a 32-pin package. In read and write modes, the chip draws less than 2 μA and 15 mA, respectively. Typical read and write cycle time is 70 ns.

During the design phase, it was considered that the addition of a SmartMedia interface could be useful to provide portable/removable data and program storage. A 3.3 V SmartMedia connector (product number MCR 102-22 RL-1.27 SF) was installed on the PCB for the SmartMedia memory card (Figures 2 and 3). The footprint of the SmartMedia connector is 40 mm by 38.5 mm by 3.0 mm. The metal cover of the connector is electrically grounded to the PCB.

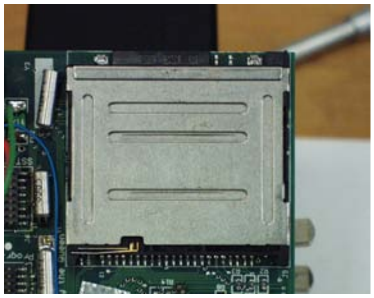


Figure 2. SmartMedia connector and card socket

Figure 3. 32 Mb SmartMedia card

At the moment, the SmartMedia memory card reader is not functional. All electrical connections to the SmartMedia connector are correct. The hardware part was implemented and tested for basic functionality. Further tests are needed on software programming.

Complex programming logic device

Two large complex programming logic device (CPLD) chips (XCR3256) from Xilinx were used to hold the logic in AMIGO. The first CPLD is used for image digitization processing and some glue logic (an ensemble of small components — gates, flip-flops — used for integrating/connecting together larger components such as a CPU and several memory chips), while the second one is used for the SmartMedia memory card interfacing. The CPLD has 256 macrocells and 6000 gates in a small 144-pin package. It is a fast chip that has less than 7 ns pin-to-pin delay. At the current operating frequency, each CPLD chip draws about 10 mA at 3.3 V and less than 0.1 mA in standby mode. A video digitizing board sends the proper synchronizing pulses (vertical and horizontal) and data stream to the first CPLD. From the synchronizing pulses, this CPLD re-combines the data and stores the value to the memory chip for further image reconstruction.

Global positioning system

A GPS module from SyChip (GPS2020) was installed in each AMIGO unit. This module is a highly integrated ball grid array chip (Figures 4 and 5) with a footprint of 11 by 14 by 3.5 mm. It uses SyChip chip-on-chip technology and a SiRF™ GPS chipset. In tracking mode it draws approximately 130 mA at 3.3 V. It has 12 receiver channels that allow fast satellite detection and positioning. It uses a ceramic active antenna mounted atop the AMIGO housing (Figures 6 and 7). The accuracy of the acquired GPS position is about 15 m. In fact, a precision within five metres was routinely obtained during testing. Once the GPS module locks on to a satellite, a GPS position can be acquired every second.

The standard deviation between two measurements in a one-second interval is always less than one metre. For longer time interval updates (5-10 min), a larger deviation of a few metres (1 to 10 m) between measurements was observed. The GPS module communicates with the CPU through a dedicated serial port (one of the two UARTs in the XR68C192). The SiRF protocol is used for exchanging commands and data between the module and the CPU.

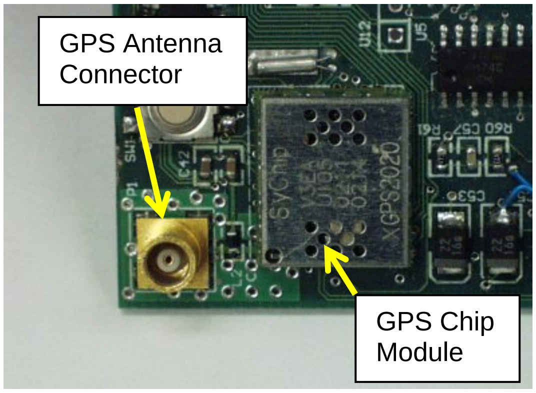


Figure 4. GPS module and antenna connector

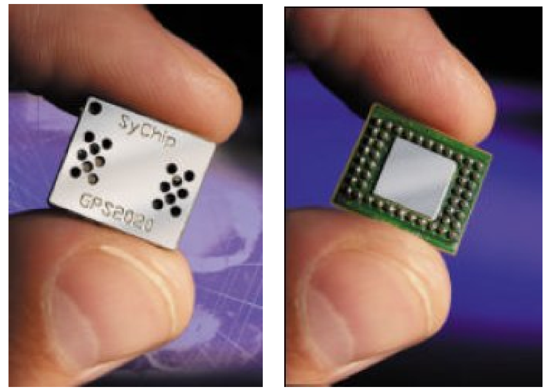


Figure 5. SyChip GPS2020 module (both sides)

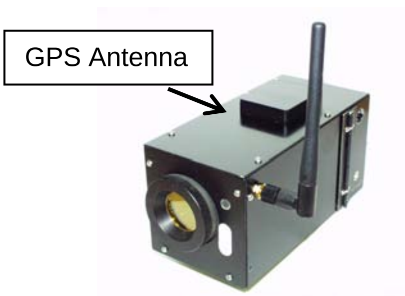


Figure 6. GPS Antenna mounted on top of AMIGO unit

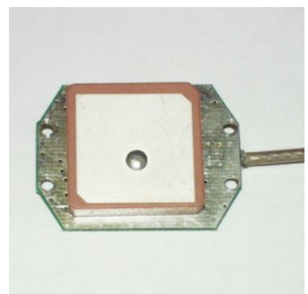


Figure 7. Ceramic Active GPS antenna

Electronic compass

In order to determine the viewing azimuth of the AMIGO imager, an electronic compass from Honeywell (HMC1022 two-axis magnetic field sensor) was installed in each AMIGO (Figures 8 and 9). By orienting the two magnetic field sensor bridge elements horizontally (perpendicular to the gravitational field), and to measure the X and Y analog voltages, the analog outputs are converted to a digital number. The arc-tangent Y/X can be computed to derive the heading.

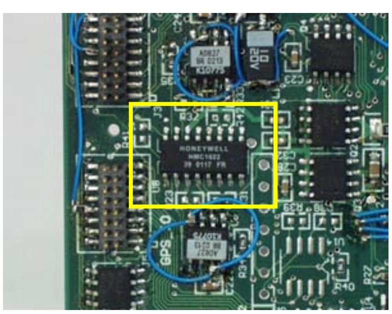


Figure 8. Honeywell magnetic sensor on the PCB

Figure 9. Honeywell magnetic sensor

Passive infrared motion sensor and triggering circuit

A low-cost PIR sensor (TR256) from KUBE Electronics Ltd. was selected as the motion sensor (Figure 10). The PIR sensor includes a dual-element, pyroelectric IR detector and a clip-on cone optics that provides 30 degrees vertical and 90 degrees horizontal FOV. This sensor has a typical detection range of 9 m for a human size target. The sensor unit draws 0.5 mA at 3.3 V. The company provided its own electronic circuit design to be used jointly for optimal results. This circuit was implemented and integrated into the main PCB and the total space required is approximately 2.5 cm^2.

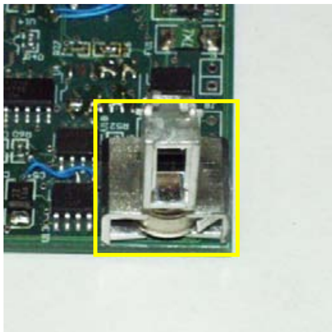


Figure 10. KUBE PIR sensor mounted on the main PCB

Acoustic sensor and triggering circuit

An electret capacitor microphone is used to detect sound at frequencies between 20 and 200 Hz (vehicle engines and footsteps) in the surrounding environment. The signal generated by the microphone is amplified using an LT1079 and filtered through a 5th-order low-pass filter using MAX280, and the resulting analog signal is compared against a DC voltage reference. The DC reference voltage controls the sensitivity and can be adjusted with a tiny potentiometer. Once the level of the analog signal is higher than that of the DC reference voltage, a pulse stream is generated. The triggering pulse stream is then transferred to the main board through a 2-by-8 Samtec connector. All these functions are performed with the acoustic triggering circuit (Figure 11). The signal is then processed by the CPU, which sends an alarm (interrupt signal) to the AMIGO interface. The MAX280 only works with 5 V, so a 78L05 low-power voltage regulator was added on the circuit. The overall current consumption of the circuit is <1 mA.

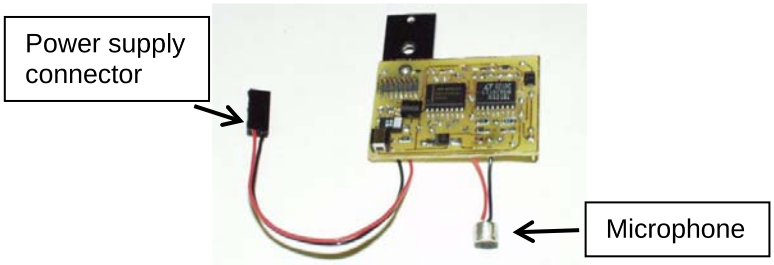


Figure 11. Acoustic sensor and its electronics

Uncooled infrared imager

The primary sensor of AMIGO is an uncooled IR imager. Two IR imager models, both from Indigo Systems, are used in two of the four prototype AMIGO units built. The first one is ALPHA, with a footprint of 4.3 by 4.3 by 11.0 cm. The second is MICRON (formerly OMEGA), with a footprint of 2.8 by 2.8 by 5.1 cm. Both imagers comprise a microbolometric, 160 by 120 pixel focal plane array (FPA) with pixel size of 51 by 51 µm. The spectral response was optimized between 7.5 and 13.5 µm. The optics of the camera consists of a Ge objective with an F-number of 1.6 and focal length of 11 mm, providing a field of view of 40 degrees in horizontal and 30 degrees in vertical. The greyscale of each pixel is 12-bit coded (14-bit in MICRON) and is stored in two bytes. Therefore, the size of an uncompressed image is 40 Kbytes. The nominal power consumption of the imager is about 1.5 W.

Video digitizing board

To allow the use of other types of cameras that have standard analog video output (NTSC, PAL, etc.) as low-cost CCD cameras in AMIGO, an analog-to-digital circuit was designed and fabricated. This circuit converts an NTSC monochrome video signal to a digital format of 160 by 120 resolution with 256 grey levels. Both Indigo IR imagers used in the AMIGO modules have an NTSC monochrome video signal output. The CPLD on the main PCB performs the task of grabbing this data and storing it in memory.

The principle of operation of the video digitizing board is as follows. Each image is digitized from one video frame. The video digitizing board has to extracts the image pixel by pixel and line by line. To do so, the signal is first scaled with the DC-restored video amplifier (EL4089), which restores the signal DC level. A video sync extractor (EL4583) extracts the synchronizing pulse and sends the signal to a phase locked loop (PLL) (MC44145) and the CPLD (ATF1504ASL). The PLL generates a stable pixel clock frequency for A/D sampling and some glue logic is required to generate the proper timing for the A/D converter (BT218). The CPLD then generates the sampling signal for the video A/D converter, based on the image size and timings.

Figure 12. Bottom side of the video digitizing circuit

Figure 13. Top side of the video digitizing circuit

After the conversion, the 8 bits data output value is forwarded to the same CPLD that splits the 8 bits into two nibbles (4 bits) needed for AMIGO. The resulting digital image should be160 by 120 pixels and have 256 grey levels. The final circuit's size is approximately 2.5 by 2.5 cm. Both sides of the circuit are shown in Figures 12 and 13.

RF transceiver

The WIT2410 RF transceiver from Cirronet was selected for wireless communication. This frequency-hopping spread spectrum (FHSS) transceiver provides wireless connectivity for either point-to-point or multipoint-to-point application. One transceiver was installed in each AMIGO and one was connected to the serial port of a computer set up as the base station. FHSS technology ensures maximum noise resistance, multi-path fading immunity, and robustness in presence of interfering signals, and most importantly, low probability of detection and interception (LPD/LPI). A detailed description of the transceiver and its antenna was reported in a DRDC Technical Note [1].

It is noted that the WIT2410 uses Ethernet protocol 802.11, which refers to a family of specifications developed by the IEEE for wireless local area network (LAN) technology. Protocol 802.11 specifies an over-the-air interface between a wireless client and a base station or between two wireless clients. The IEEE accepted the specification in 1997. As the next-generation 802.11a, 802.11b and 802.11g, which allow mesh or ad-hoc network communication in a multi-node configuration, are becoming available and popular, these improved protocols will be considered in future developments.

Power management and batteries

Two C-size 3.3 V batteries are connected in series and 6.6 V was available to the system. The voltage level required by the main PCB is 3.3 V while the IR imager requires between 8 and 12 V. One DC/DC step-down converter (MAX1651) reduces the voltage to 3.3 V for the main PCB and a second DC/DC step-up converter (MAX1771) increases the voltage to 7 V for the IR imager. It was later found that the two 3.3 V batteries were not sufficient to maintain the voltage level for the camera during the 0.5-second camera shutter activation for self-calibration. As a result, only the AMIGO units without the IR imager were configured for the C-size batteries (Figure 6). The AMIGO with imager uses two more powerful 4.25 V LC3135A rechargeable batteries held in an extra battery holder underneath (Figure 14).

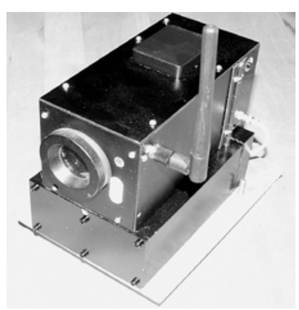


Figure 14. AMIGO with battery holder underneath

The 8.5 V from the two batteries is lowered to 3.3 V for the required voltage level on the PCB circuit. A step-down converter was preferred, since a normal voltage regulator will waste over 50% of the battery power. The step-down DC/DC converter has an 80% to 90% efficiency, which is much more acceptable. However, due to the switching nature of the step-down converter, noise was present at the output of the converter. This noise level is approximately 10 mV RMS (root mean square). The digital circuitry of AMIGO is not affected by this line noise. However, it may cause unwanted false triggers of the audio and PIR circuitry.

System architecture

Each component introduced previously in the hardware section requires electronic sub-systems to warrant its functionality. In the following section a description of these sub-systems and the hardware architecture are presented.

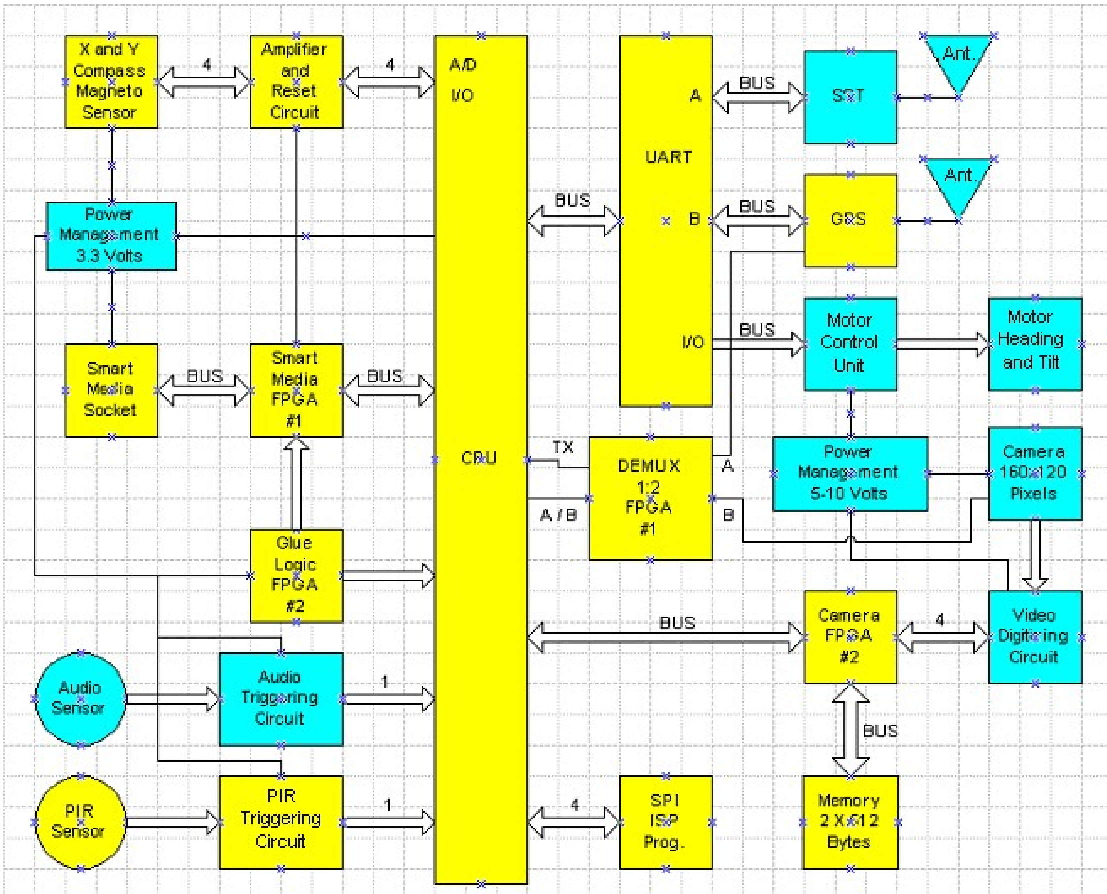


Figure 15. Block diagram of AMIGO architecture

Block diagram

The detailed system architecture of AMIGO is represented in the block diagram shown in Figure 15. The blocks that appear in yellow/lighter colour are components that are integrated into the main PCB while the rest (blue/darker) are external boards connected to the PCB. External components such as the transceiver, motor control unit and acoustic circuitry are linked to the PCB with FFSD Samtec connectors. In the current design, there are extra cables that deliver power to the acoustic board, the video board, the IR imager and motor driving circuit. These cables were connected directly to the step-up and step-down converters.

PCB design and fabrication

The design and fabrication of the final PCB was done using Protel 98 SE. The schematics shown in Annex A.1, A.2, and A.3 are the final circuit of the system. From these three schematics, a four-layered PCB was fabricated by Caladena Group (Pointe-Claire, Quebec). Most components on the PCB are surface-mounted. With the exception of the GPS module, they were mounted by DRDC personnel. The GPS module is a BGA chip that must be mounted on the PCB with a special heating process. This was performed at Caladena.

The resulting PCB with all the parts soldered and major bugs corrected is shown in Figures 16 and 17. As the photos show, minor bugs in the original design were corrected with wire-wrapped cable. Most bugs were corrected on the final schematic as well.

Figure 16. AMIGO PCB (bottom side)

Figure 17. AMIGO PCB (top side)

AMIGO assembly

The AMIGO assembly was designed by Prototyping Service Group at DRDC Valcartier. A 3D view of the AMIGO unit is shown in Figure 18. The AMIGO drawings can be found in the Prototyping Service Group files under reference numbers 02062601, 2062606 and 02062623.

The final assembly prototype is slightly different from the 3D drawing presented here, since minor modifications were made since that drawing was created. Most of these modifications involve the SST and GPS antenna location. Now the spread spectrum transceiver antenna is a whip antenna located on the left side of the unit. A ceramic active GPS antenna is mounted atop each module. A GPS antenna cover and a separate top plate were custom-made.

The design shown here includes two C-size internal batteries. In the case of AMIGO with IR imager, external batteries are used (Figure 14). The schematic of the battery holder can be found in the Prototyping Service Group files under file reference number 04012201. Some internal components are shown in Figure 19.

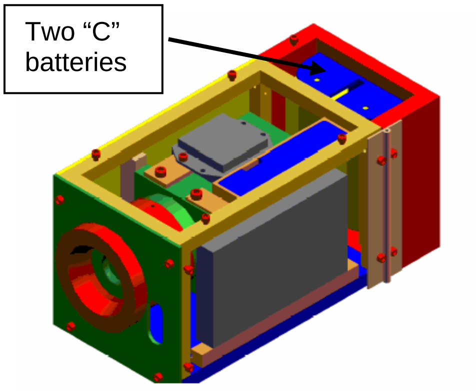


Figure 18. AMIGO 3D drawing

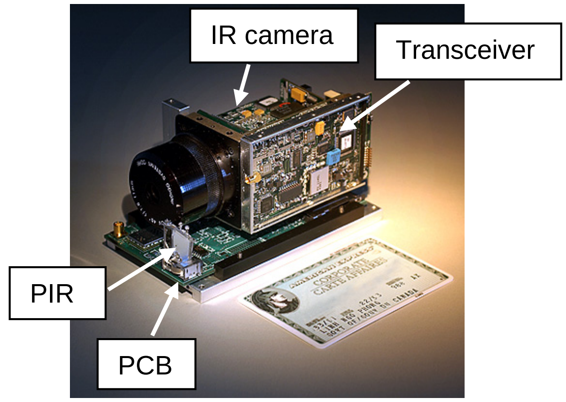


Figure 19. Final assembled AMIGO unit showing the internal components

Firmware programming

The microcontroller firmware controls all operations in the AMIGO units. It was programmed in C. A customary communication protocol was developed based on the transceiver protocol. In this protocol, the AMIGO unit communicates with the base station by the use of primitives (an ensemble of messages exchanged between systems) of different length according to the primitive type. A set of primitives was implemented first as a core to access the different capabilities of the AMIGO unit. Further primitives were then developed as needed.

Hardware programming

Some AMIGO functionalities were implemented with programmable devices. The SmartMedia interface is implemented in one CPLD, and the glue logic is implemented in the other CPLD. Both CPLDs (Xilinx XCR3256) were coded in VHDL. The code is compiled and downloaded into the CPLD through the JTAG interface with the WebPACK software from Xilinx. In the video digitizing board, the video converter was coded in CUPL, compiled with WinCUPL and downloaded into the CPLD (ATF1504ASL) with WinISP.

Monitor and control interface

A monitor and control interface (MCI) consists of an RF transceiver and a laptop running a GUI. Its program controls the transceiver through the serial port. The GUI displays AMIGO information and provides a command and control interface.

Software operation

The MCI program was developed using Borland 6 C++ Builder. Besides the built-in libraries, three extra library components were installed. These are XPmenu, TMS Async32 and TatukGIS. The XPmenu library allows the use of XP style menus, toolbars, buttons and other controls. TMS Async32 controls data sent or received asynchronously through the serial port, allowing other tools to run in the background. TatukGIS from SDK software is used to display layer-by-layer geo-referenced information such as maps and aerial images. Various image formats can be read using this component.

The MCI software internal structure is shown in Figure 20. There are different classes that interoperate with each other. Some classes represent the visual aspect of the interface while others work in the background.

Within the classes that work in the background, the most important one probably is the Remote class. The Remote class contains information on each AMIGO. It was further divided into sub-classes: Audio, Camera, Compass, GPS, PIR, RTC and SST. Each sub-class has distinct properties. For example, the Camera sub-class has properties (also known as member variables) related to the camera status such as brightness, contrast, image, imagelist, imagetemp, etc. Each sub-class also contains functions to allow the reading or writing of object properties such as readcontrast, writecontrast, readbrightness and writebrightness, etc. When a new AMIGO unit joins the network, these functions are used to read and write the member variables.

When information is received from an AMIGO unit, the Remote Control class controls and dispatches the information received by the MCI through the TMS Async32 serial thread. This class works closely with the Read and Write Serial classes, the AMIGO Message class, and the Transfert Form [“Transfer” is misspelled in the software.] class. The serial thread receives information formatted in three different packet types: connection packet, disconnection packet and data packet. Depending on the packet type, the information is treated accordingly and dispatched to the proper class units. For example, when a connection packet is received from a new AMIGO unit that has not been registered in the MCI, a new unit is declared in MCI automatically allowing reading or writing of any of its properties. And when a disconnection packet arrives, the Remote Control class makes the AMIGO unit appear disconnected in the MCI and disables all its properties. When a data packet arrives, the data part is decoded and dispatched to the proper Remote sub-classes.

The Remote Control class also controls the information sent to individual AMIGO units. It transfers the information to the AMIGO Message class that processes and creates the message. When the message is created, it returns to the Remote Control class and it is then sent to the AMIGO units through the Write Serial. In the current design, the baud rate was set to 112 kbps, which is the maximum baud rate of the transceiver.

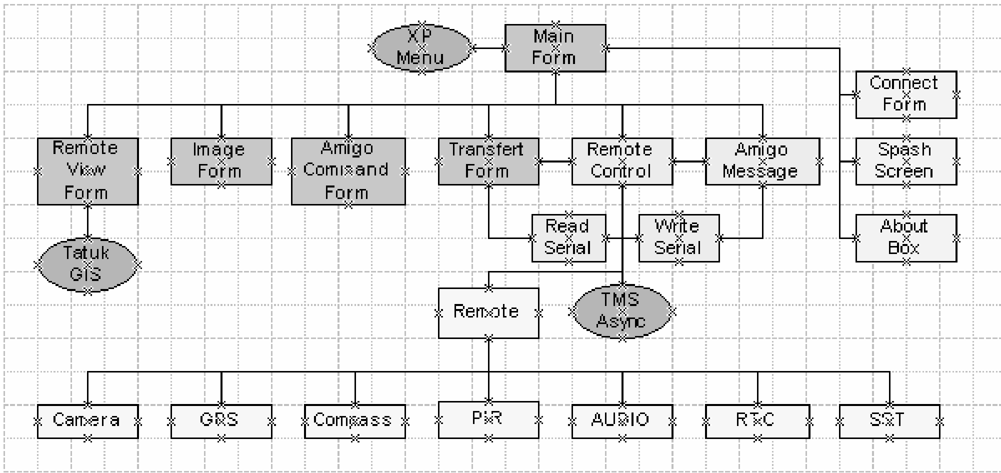


Figure 20. Histogram of the AMIGO software architecture

Graphic user interface

A snapshot of the GUI is shown in Figure 21. The GUI consists of five main classes. They are the Main Form and four other classes: AMIGO Command Form, Image Form, Remote View Form and Transfert Form. These five classes translate into five distinct windows. There is the main window (Main Form), the activity window (AMIGO Command Form), the image window (Image Form), the viewer window (Remote View Form) and the command window (Transfert Form).

The viewer window displays a map or an aerial view of the AO. Upon receipt of a compass or GPS reading from AMIGO, the end user can see the position and orientation of each AMIGO on the aerial map. This window has features such as zoom in, zoom out, extend, etc. Different layers can also be set transparent, and the properties of a specific AMIGO unit can be displayed in the command window.

The command window has two major functions. The first function is to send requests or commands to AMIGO units. For instance, the user can retrieve IR images from AMIGO. The commands can be sent to one AMIGO or all units at the same time. The second function of the command window is to display AMIGO properties. After an image transfer request, the downloaded image will appear in the image window (Image Form). Two images can be visualized simultaneously. On each acquisition, it is possible to add the current date and time to the image. An additional feature allows the operator to use triangulation to estimate the location of objects appearing in the images. Knowing the geo-positions, headings and FOVs of two AMIGO units taking IR images, the operator can estimate the positions of objects of interest.

The activity window (Amigo Command Form) shows the activities going on between the base station and all AMIGO units. When a request is sent, the user can check the window to see if there is a response. The user can also monitor all detections received from all AMIGO units. This window is especially useful in the debugging process.

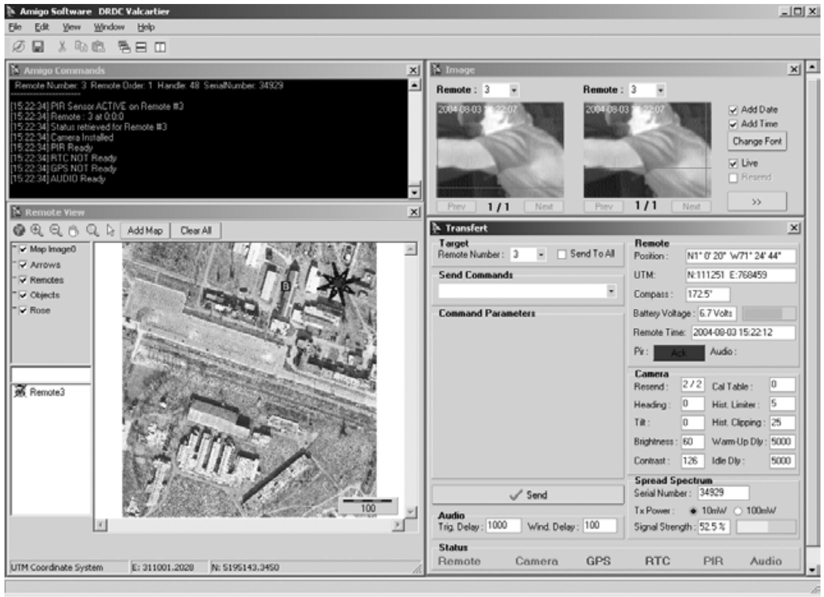


Figure 21. Snapshot of the AMIGO GUI

Trials and results

According to the wireless communication test results [1], various surveillance senarios were composed to assess the capabilities of AMIGO. These scenarios include personnel and vehicle proximity (motion or sound) detection and target image acquisition, multiple target imaging for target GPS position estimation, entrance event counting, indoor surveillance, real-time GPS position tracking, and aerial surveillance using a radio-controlled model plane. All tests were performed in LOS, partial-LOS or non-LOS settings. All tests were carried out during daytime. Since the vertical level or the height of AMIGO has an effect on the performance of wireless transmission, AMIGO units were also tested on tripods and directly on the ground for performance comparison (Figure 22). Four AMIGO units were available for the tests. All AMIGO units (A-1, A-2, AI-1, AI-2) are equipped with passive IR motion sensor, acoustic sensor, electronic compass, GPS and wireless transceiver. Two of the four (AI-1 and AI-2) were also fitted with an uncooled IR camera (Figure 23).

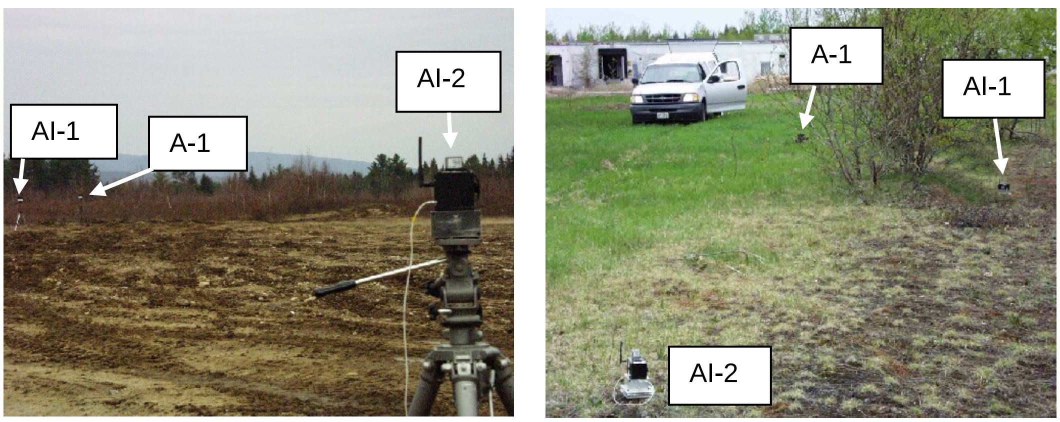


Figure 22. AMIGO sensors deployed on tripods and directly on the ground

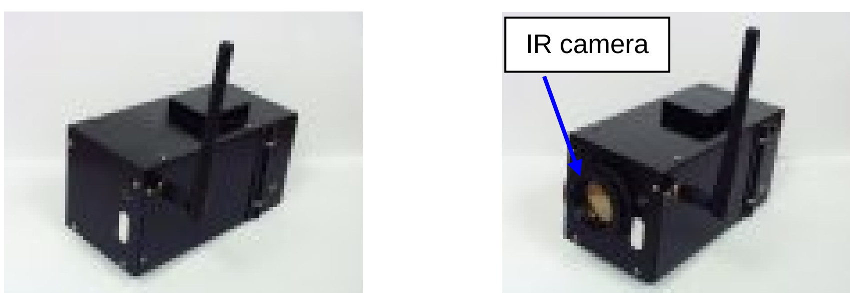


Figure 23. AMIGO units with and without IR imager

Personnel and vehicle detection

The basic sensor deployment is to use an AMIGO unit to detect personnel or vehicle intrusion leading to instantaneous target image acquisition. This idea can be demonstrated using the sensor configuration shown in Figure 24. The intrusion will be picked up by the passive IR motion sensor or the acoustic sensor of AI-1 at distances d_{PIR} and $d_{Acoustic}$, subject to sensing range. Upon detection, the target image will be captured. In a separate configuration, a second AMIGO unit equipped with an imager (AI-2) is positioned some distance away to provide wider coverage. A third AMIGO (A-1) will be used to trigger image acquisition by AI-2 upon intrusion detection. The base station is positioned at a distance D to monitor and control all the AMIGO units. The distance D will be subject to the maximum achievable wireless link between the base station and all the AMIGO units. A person acting as a target will be walking and running while a truck will be moving at different speeds toward the sensor field. Tests will be carried out with LOS, partial LOS and no LOS between base and AMIGO units. The LOS testing was conducted in open terrain with no obstructions—hills, trees, buildings and utility poles—blocking RF transmission between the AMIGO units and the base station (Figure 24(a)). In the partial-LOS and non-LOS tests, the RF link was partially obstructed (Figure 24(b)) or completely obstructed (Figure 24(c)) by buildings, as the case may be. For each group of tests (LOS, partial-LOS, NLOS), parameters such as detection distance, target type, target movement, communication range and false alarms were recorded and compared.

The LOS test was performed on the precision firing range at CFB Valcartier. This terrain offers a 100 m by 2.5 km corridor with no obstacles (Figure 25). Three AMIGO units were deployed as shown in Figure 24(a) along a track. They were either mounted on tripods or placed directly on the ground to study the effect of vertical position on the wireless communication range. AI-1 was configured to self-trigger and capture the target image, while A-1 was used to trigger imaging by AI-2 located about 40 m away. The distance from the AMIGO units to the track was varied to determine the actual target detection distance (d_{PIR} and $d_{Acoustic}$) of the PIR and acoustic sensors. The targets consisted of a person walking or running and a truck moving at speeds between 20 and 50 km/h. The base station was located from 500 m to 2.5 km from the AMIGO units to determine the reliable communication range (D).

Overall, the AMIGO system performed as expected. All AMIGO units were geo-referenced and graphically displayed by the base station GUI. Unit parameters and status were also shown. Targets were detected, leading to image acquisitions. These images were sent from the AMIGO units to the base station for display. The PIR sensors could reliably detect a walking/running person and a truck moving at 20 to 50 km/h from a distance up to 10 m. The acoustic sensor could detect a stationary truck with engine running and a truck moving at 20 to 50 km/h. No false triggers were recorded. By monitoring the RF signal strength (built-in function of the transceiver) and actual RF connectivity, the maximum distance of reliable wireless communication between the base station and the AMIGO units was determined to be 1.2 km for tripod-mounted units and 650 m for units on the ground. With the AMIGO units deployed on elevated terrain 35 m higher than the area of interest, reliable communication could be obtained at 2.5 km. As a result, users can take advantage of uneven terrain to gain extra range. Moreover, these tests showed that the units should be sited relative to the base station so that passing targets will not momentarily block the RF link.

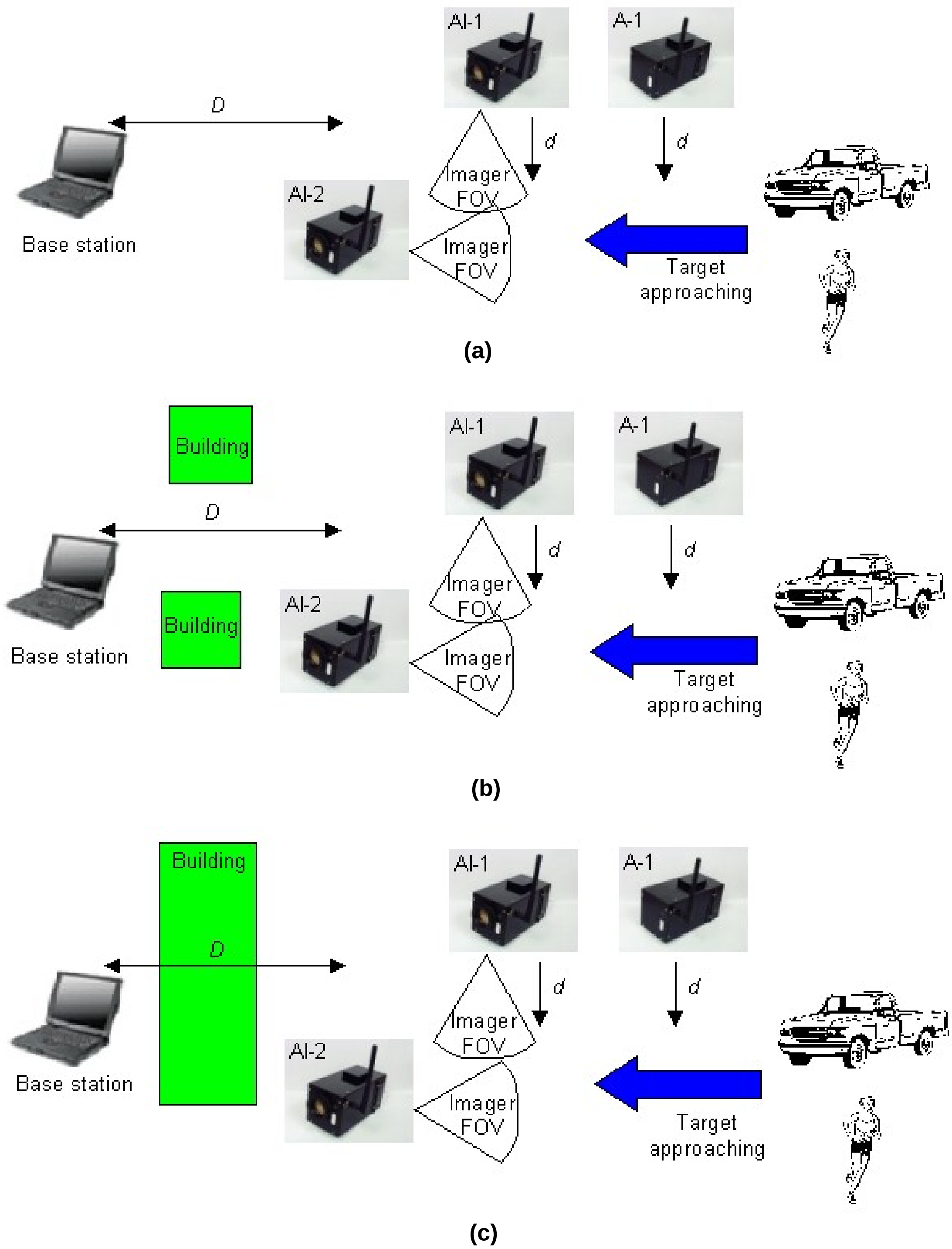


Figure 24. AMIGO sensor deployment for personnel and vehicle detection with (a) LOS; (b) partial LOS; and (c) NLOS

Figure 25. Precision firing range at CFB Valcartier

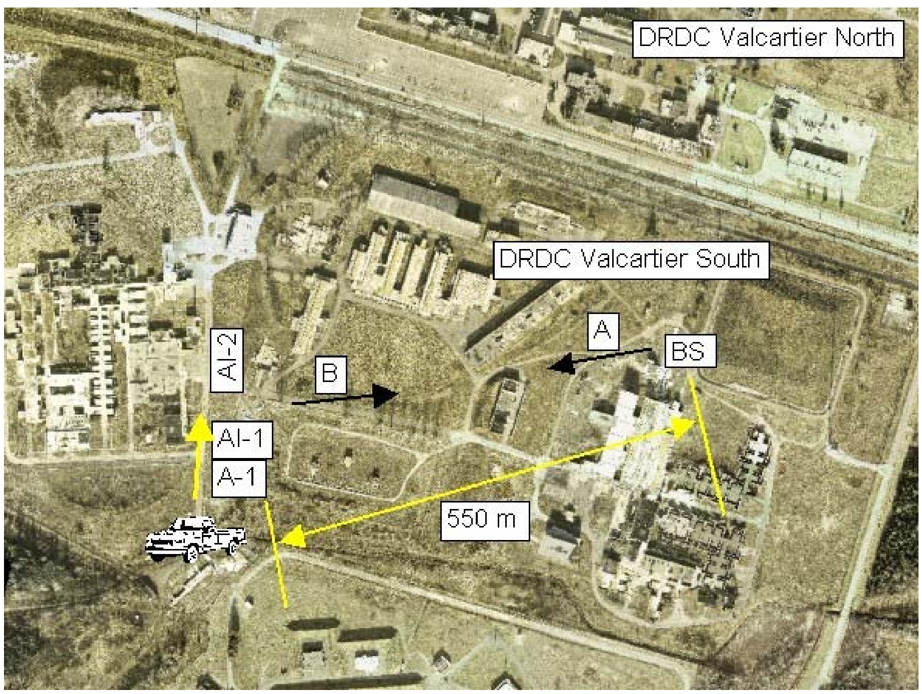


Figure 26. Aerial view showing the actual locations of the base station and AMIGO on the south campus of DRDC Valcartier in partial-LOS test

The partial-LOS test was carried out on the south campus of DRDC Valcartier. The overhead view of the area with the AMIGO unit locations is shown in Figure 26. With the same AMIGO unit configuration as in the LOS test, the base station (designated as BS in Figure 26) was located several hundred metres away. Between the sensors and the base station were two buildings acting as obstacles to establish the partial-LOS condition. The view from the base station to the AMIGO units (arrow A in Figure 26) is shown in Figure 27(a), and the view from the AMIGO units to the base station (arrow B in Figure 26) is shown in Figure 27(b).

(a) (b)

Figure 27. Pictures showing (a) the view from base station to sensors (arrow A in Figure 26) and (b) the view from sensors to base station (arrow B in Figure 26)

(a) (b)

(c) (d)

Figure 28. IR image taken from (a) AI-2 of a moving truck; (b) AI-2 of a running person; (c) AI-1 of a moving truck; and (d) AI-1 of a running person

Figure 28 shows the target IR images upon the PIR sensor triggering. The range (straight-line distance between BS and sensor field — between the two lines in Figure 26) is 550 m with AMIGO on tripods and 360 m on the ground. In the NLOS test, AMIGO was in the same location but the base station was moved behind a building, completely blocking the LOS between AMIGO and the base station (Figures 29 and 30). The achievable ranges were 175 m with AMIGO on tripods and 150 m on the ground. No false alarms were recorded in either test sequence. The surveillance test results with LOS, partial LOS and NLOS are summarized in Table 2.

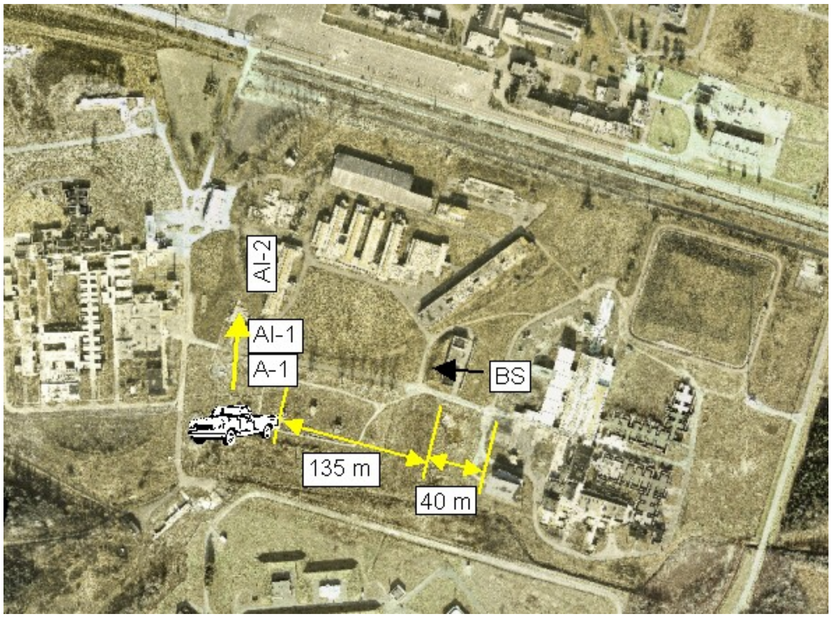


Figure 29. Aerial view showing the actual locations of the base station and AMIGO in NLOS test

Figure 30. Photo showing the view from the base station toward the building blocking the LOS to the sensors

Table 2. LOS, partial-LOS and NOLS surveillance test results

	LOS	PARTIAL-LOS	NLOS
Passive IR motion sensor **Maximum detection range d_{PIR} (m)**			
- Personnel walking/running - Vehicle moving at 20–50 km/h	8 10	Not applicable Not applicable	Not applicable Not applicable
Acoustic sensor **Maximum detection range $d_{Acoustic}$ (m)**			
- Vehicle moving at 20–50 km/h	20	20	20
Maximum comlink distance D (m)			
- AMIGO on tripod - AMIGO on ground	1200 550	550 360	175 150

Target triangulation

From the GPS positions of two AMIGO units and the corresponding target images, it is possible to determine the geo-position of the target if the viewing azimuth (electronic compass) and FOV of the imagers and the position of the target in each image are known. This procedure is called triangulation. It is preferable to know the precise target position, especially if there are multiple targets, for mission planning or to take effective action. It is noted that at least two AMIGO units equipped with imager must be used to perform triangulation. In Figure 31, one non-imager AMIGO (A-1) is used to trigger two AMIGO imager units (AI-1 and AI-2) at two locations to take images when personnel or vehicles are detected. By clicking on the target in the images at the base station, the position of the target in each image is registered by the software and the triangulation is processed. The output is the GPS position of the target. The target position computed by triangulation in this test was compared with the target position determined with a handheld GPS device.

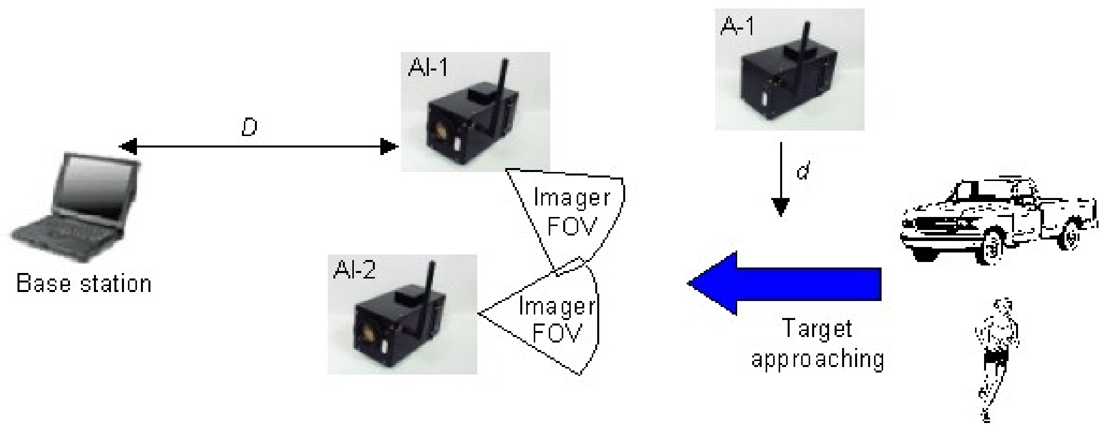


Figure 31. AMIGO sensor deployment for target triangulation

This test was performed in Parc Lemay at DRDC Valcartier with LOS between the base station and the AMIGO units. The aerial view and hardware locations are shown in Figure 32. Unit A-1 was placed on the roadside while AI-1 and AI-2 were deployed between 140 and 230 m from A-1. As the target passed A-1, it detected the target movement and triggered AI-1 and AI-2 to take images in the direction of A-1. From the AMIGO positions, viewing azimuths, imager FOVs and the positions of the targets in the images, the base station determined the geo-position of the target. The triangulated positions were then compared with a handheld GPS device output. After several test rounds with different AI-2 positions, the results showed that the GPS position of the target could be estimated with an accuracy of two metres with the current system specifications. According to the specification of the GPS2020 module, the typical position accuracy is 15 m. In fact, a precision within five metres was routinely obtained during testing. The reason for the 2-m positioning accuracy may be the different operating conditions or that the manufacturer underestimated the instrument accuracy.

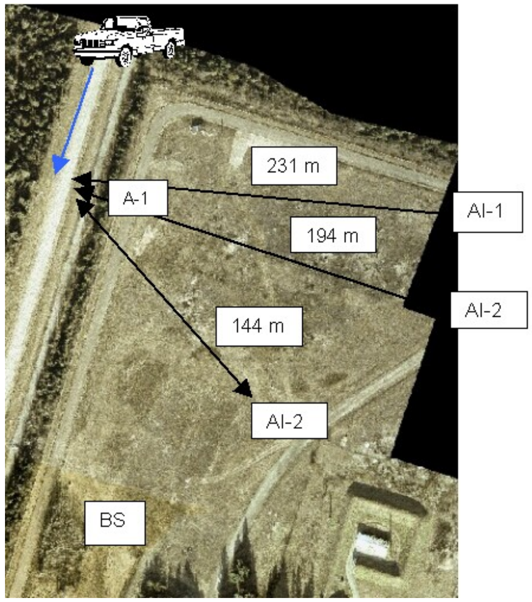


Figure 32. Aerial view showing part of Parc Lemay and the AMIGO locations for the triangulation test

Entrance surveillance in urban environment

Due to the many structures in urban environments, there are many pockets of NLOS terrain that prevent the use of traditional, long-range electro-optical (EO) surveillance. It is also difficult to establish reliable wireless communications in built-up areas. A dispersed sensor network can be used to provide short-range LOS and NLOS surveillance to complement long-range LOS surveillance, and to provide continuous round-the-clock monitoring of gaps between sub-units, roads, city blocks, and within unit areas of operations. Operators can maintain remote observation via the GUI at the base station. In this surveillance test, AMIGO units were set up to monitor NLOS strategic points such as facilities and building entrances in order to demonstrate the use of AMIGO to remotely monitor and count events in an urban environment. Parameters such as detection distance, communication range and false alarms were recorded and compared.

Two tests were performed on the grounds of DRDC Valcartier. The first test was to monitor traffic at the two personnel entrances to DRDC Valcartier property. The second test was to monitor the traffic entering and exiting a building. In both tests, A-1 and A-2 were configured to trigger AI-1 and AI-2 for image capturing. With AI-1 and AI-2 positioned further away from the two target areas than A-1 and A-2, a wider region could be covered for imaging.

For entrance monitoring in the first test, the AMIGO deployment is shown in Figure 33. The base station was located inside a building used as a command post. The base station antenna was also located inside that building. The straight-line distance from the base station to Entrance #1 and #2 are about 130 and 180 m, respectively. All AMIGO units were placed on the ground. Upon PIR sensor triggering of A-1 and A-2, IR images (shown in Figure 34) were taken by AI-1 and AI-2. No false alarms were recorded.

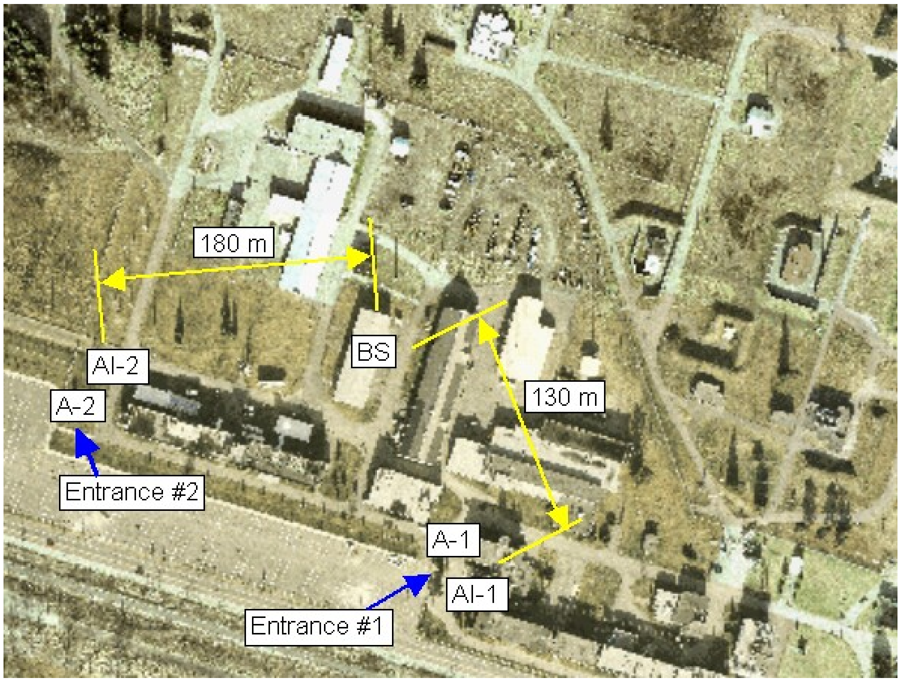
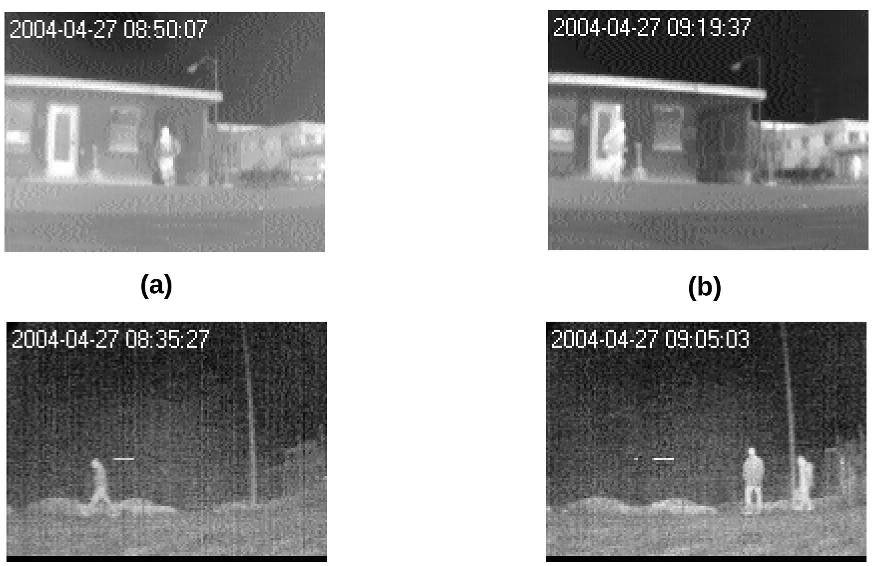


Figure 33. Aerial view showing the actual locations of the base station and AMIGO units in entrance monitoring test



(a) **(b)**

(c) **(d)**

Figure 34. IR images taken by AI-1 of Entrance #1 and by AI-2 of Entrance #2 upon A-1 and A-2 triggering

The second test was to monitor a building entrance. A-1 was positioned on the ground about four metres from the entrance, while AI-1 was mounted on a roof-top tripod looking down at the entrance (Figure 35). As personnel passed the entrance, the PIR sensor of A-1 picked up the signal and triggered AI-1 to capture the image (Figure 36). No false triggers were recorded in this test.

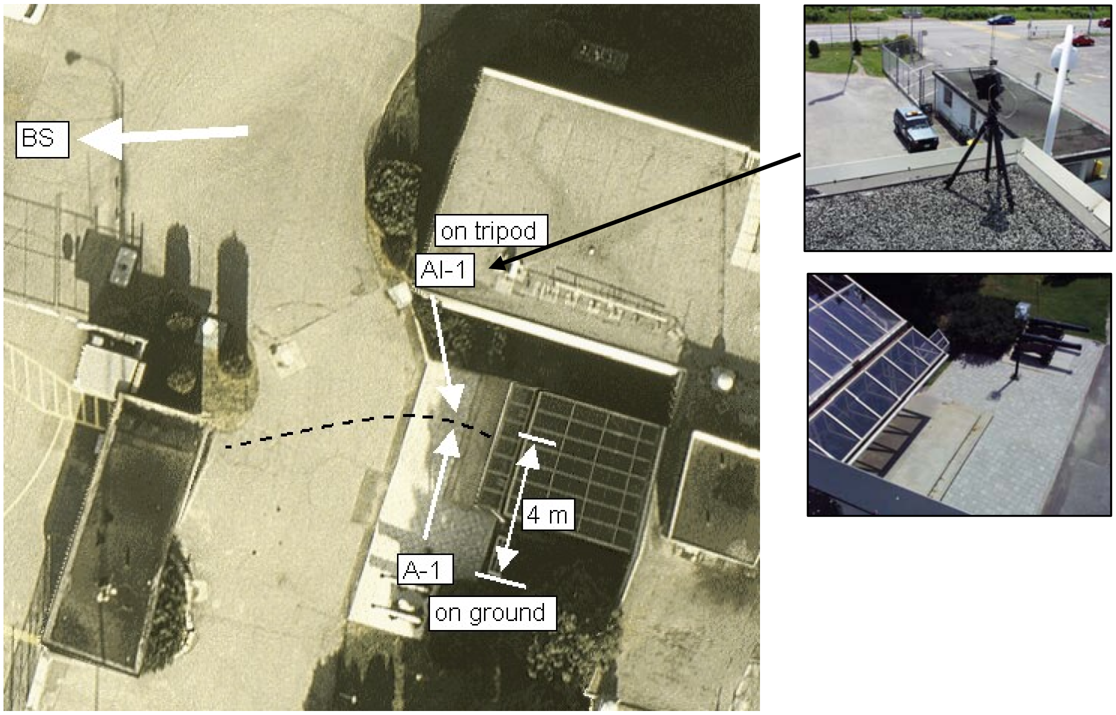


Figure 35. Aerial view showing the entrance of the monitored building and the corresponding AMIGO locations, and inserts showing AMIGO on tripod and its view

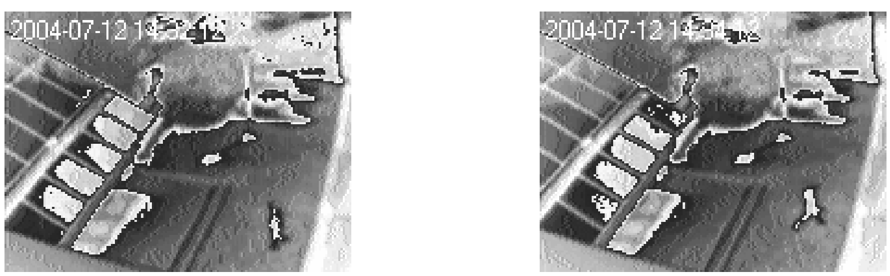


Figure 36. IR images taken by AI-1 when triggered by A-1

Indoor surveillance

One of the most challenging tasks in urban reconnaissance missions is to perform surveillance inside a building from a standoff location. A building interior is not only an NLOS area that prevents long-range EO interrogation, but the enclosed environment also significantly degrades wireless transmission, making it difficult to relay information from inside to outside. In this test, AMIGO was evaluated for its indoor surveillance capability. At least one AMIGO was positioned inside a closed compound while the base station was set up at a standoff location outside. Parameters such as detection distance, communication range and false alarms were recorded and compared.

This test was performed by placing AI-1 inside a building eight metres from the entrance. The base station was outside about 100 m from the building (Figure 37). Images were taken upon personnel detection (Figure 38). All entries were detected and no false triggers were recorded. Signal reception quality at a range of 100 m was consistent with that observed in the NLOS test at 150 m, where AMIGO units were located in open terrain. Longer ranges could be achieved by increasing RF power or using a repeater to relay the RF signal.

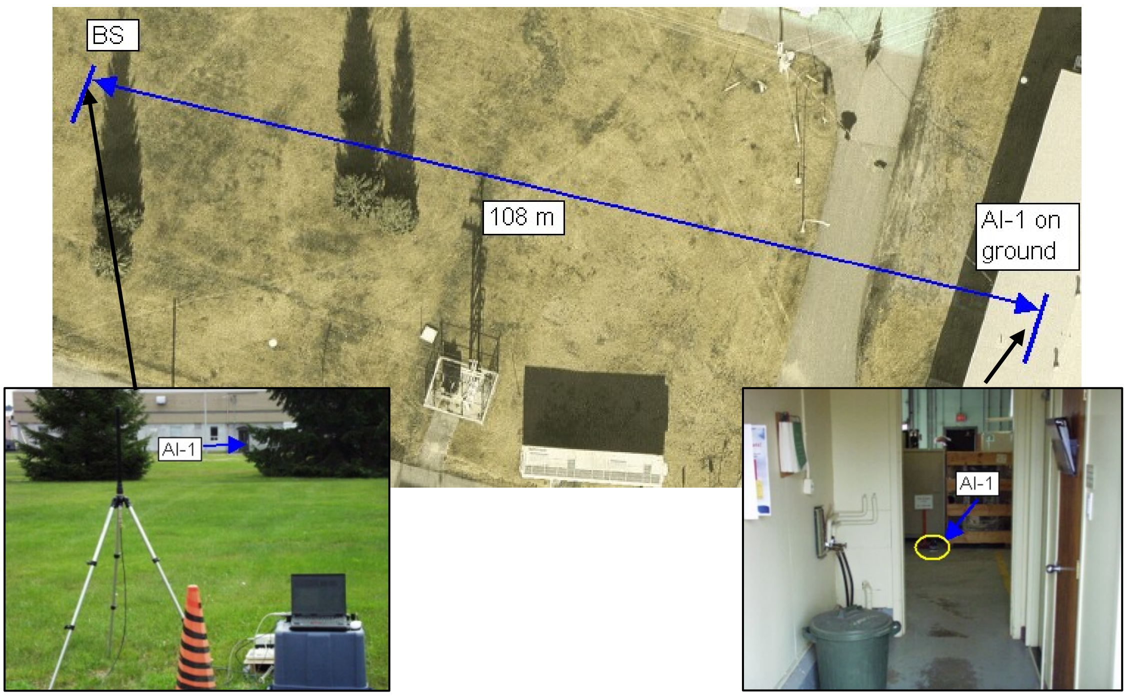


Figure 37. Aerial view showing the monitored building and the corresponding AMIGO and base station locations, and inserts showing AMIGO on the floor inside the building and the base station looking towards the building

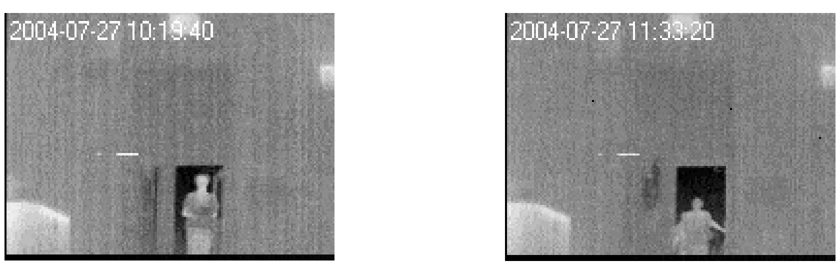


Figure 38. IR images taken by AI-1 upon triggering

Real-time position tracking and mobile surveillance

The goal of this test sequence was to demonstrate the capability to instantaneously convert a manned or unmanned vehicle into a geo-referenced, mobile surveillance platform using a compact system such as AMIGO. This could be achieved by mounting an AMIGO unit on a truck, boat, aircraft or robot. For example, one could use AMIGO units to remotely monitor the movement of convoys and upload images. Since all the required sensors and electronics are in a single package, no special installation on the designated platform is needed. The platforms tested were a truck and a radio-controlled model plane. The GPS positions, directions of movement and images were recorded in these tests.

Two tests were performed. In the first test, an AMIGO unit was placed in a truck that was driven around the buildings in the north sector of DRDC Valcartier. With the GPS tracking function selected, the GPS position of the truck was automatically transmitted from AMIGO to the base station about every five seconds. The corresponding truck positions were displayed at the base station on a geo-referenced aerial image of the area. In the second test, an AMIGO unit (Figure 39(a)) was installed in a radio-controlled model plane (Figure 39(b)), a SIG Kadet, 80-inch wingspan, 6-lb. dry weight without payload, to demonstrate the aerial surveillance concept. This test was performed in Area 14 of the CFB Valcartier training area. The geo-referenced aerial image of Area 14 was used to display the plane location in real time at the base station. The electronic compass also allowed the aircraft heading to be graphically displayed. The plane was controlled by an operator flying a serpentine pattern over a 300 m by 300 m area at an altitude of approximately 30 m. Real-time images of some ground targets were recorded for evaluation. In this first flying test, it was quite challenging to take a ground image from the air. It was difficult to maintain stable flight for imaging and also to time the image capture to ensure the target on the ground is included in the image. In many imaging trials, the target was not captured. In addition, the vibration of the plane resulted in jerky images. Figure 39(c) shows a truck on the ground that was captured during a flying test. A mechanism to reduce the effects of carrier vibration on the imaging process is required. Another problem was the reliability of wireless communications between AMIGO and the base station. The wireless link was often broken during airborne testing. The reason is that the original antenna of AMIGO system was optimized for ground operation. The electromagnetic (EM) wave pattern of this antenna has a doughnut-like shape propagating horizontally, allowing it to cover a large ground area. With an AMIGO unit in the air and the base station on the ground, the EM wave weakened so much, even at a relatively low attitude, that communication problems resulted. This problem could be solved easily by replacing the antennas in airborne units to provide the required EM wave coverage for air-ground communications.

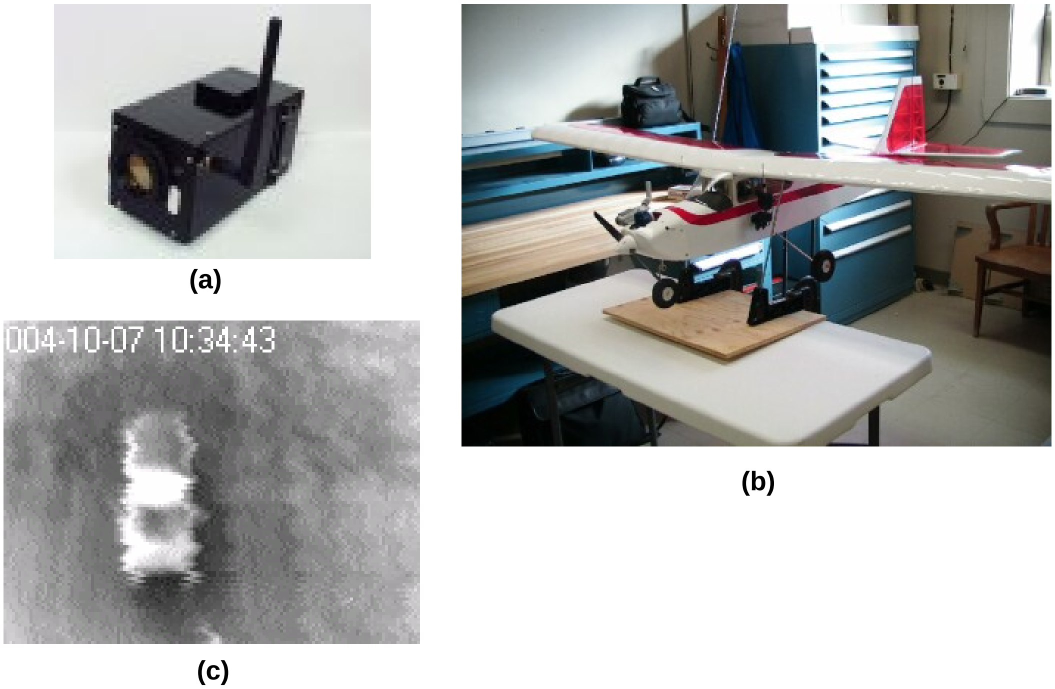


Figure 39. (a) An AMIGO unit; (b) the radio-controlled model plane used in the flying test; and (c) an IR image of a truck taken during the flying test

Discussion, conclusions, and future works

Discussion

The need for remote ground sensors (RGS) or unattended ground sensors (UGS) in military operations has been identified since the Vietnam War. During that conflict, sensors (e.g. REMBASS) were deployed to detect phenomena created by human activity. There were some successes, but there were also many false alarms and misinterpretations which hampered decision-making and, in many cases, negated the advantage of the RGS.

In current operations, it is clear that the main objective of using UGSs is to improve situational awareness for soldiers and commanders so that best decisions can be made. To achieve optimal situational awareness, these sensors must provide timely, accurate, useful, comprehensive and sufficient information to the users. This objective can only be achieved with thorough understanding of sensor technologies, data processing, information management, human-machine interface, command and control, RF communications and node networking. Details of the mission are also essential (expected phenomena, characteristics of area of operations, etc.) so that sensors can be deployed to best effect. Although an extensive multidisciplinary effort has been committed to improving UGS functionality, these sensors are still far from optimum.

Here is an example. As one of the systems accepted and fielded by today's military forces, four sets of Classic 2000 UGS from Thales were acquired by the CF and deployed in Afghanistan in 2004. This UGS has passive IR sensors for direction of arrival (DOA) detection, magnetic sensors for vehicle detection, seismic sensors for footsteps and running vehicle detection, and tripwires for passing vehicle detection. These sensors report detection wirelessly to a handheld monitor that displays alarms. All sensors report every detection to the monitors. The seismic sensors provide target classification such as personnel and wheeled or tracked vehicles, while the PIR sensors provide target DOA. The standoff distance between sensor and monitor is up to 5 km, and this distance can be extended by repeaters. The wireless transmission uses burst mode that is fairly difficult to detect and intercept. According to the types and sequences of detection, operators can interpret the intrusion as to number of targets, classification, DOA and speed. False alarms can also be discriminated. The size of the sensor is roughly that of a take-out hamburger box. The sensor battery life was documented at a maximum of 50 days. According to technical personnel at Thales, this is based on four activations, alarms or transmissions per hour. This translates to a total of 4800 transmissions.

These sensors provide acceptable sensing capabilities, but the operator must examine each and every detection to decide whether it is an actual intrusion, and then interpret the number of targets, target classification (in the case of non-seismic detections) and so on. This is a heavy workload for the operator. It not only requires personnel to monitor numerous sensors, but also it takes time to interpret and verify the types of intrusion. As a result, timely, accurate and useful information is not guaranteed.

Strategies are available to improve UGS effectiveness. In terms of interpretation, if the deployed sensor transmitted an image it would substantially increase the confidence level of target detection, classification and identification. This view was echoed by CF members after the trial of the Classic 2000 UGS in Afghanistan. In a more recent development, Classic 2000-type sensors were used to cue a station equipped with gimballed visible and IR imagers (Terrain Commander from Textron Systems US).

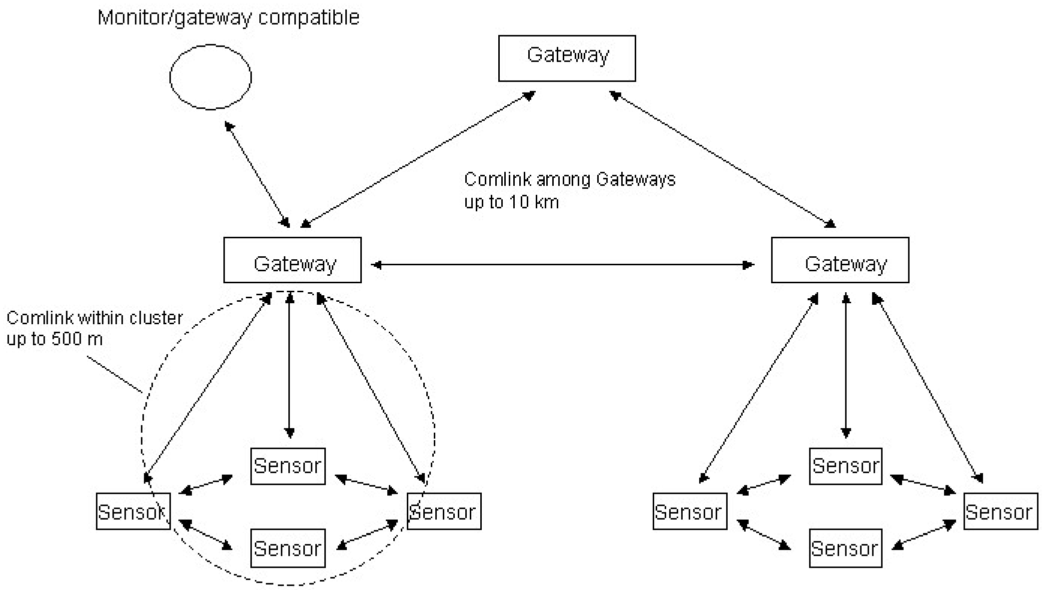


Figure 40. Concept of UGS architecture

The authors would like to propose the following features for an optimal future UGS system. A generic UGS configuration is shown in Figure 40. It consists of sensors and gateways, with a cluster of sensors operating under each gateway. Various numbers of sensor between 10 and 1000 could be deployed by hand or by air drop. In the latter case, each sensor location would be uploaded via an integrated GPS module. Without prior programming, each sensor has its identity (name or number) recognized once activated so that command posts and other portable monitors (equipped with gateways) carried by soldiers on the terrain can identify the sensors and correlate the information they generate. Unlike existing UGSs that send every detection to the command post, a more enhanced UGS will have multiple sensors that cue each other to improve overall detection, classification and identification capabilities. The false alarm rate would also be reduced. An imager should be added to the system to improve the confidence level. Sensor cueing leads to data processing with algorithms that are designed according to expected phenomena and common sense factors like the sequence of events. Some processing would be done collaboratively by the sensors. If it is determined that an alarm is legitimate, a message would be sent to the command post. This reduces the volume of communications between the sensors and command post to minimize power consumption and bandwidth usage.

In a more advanced configuration, targets would be classified, identified and counted with different types of sensors using both imaging and non-imaging data through correlation, automatic target detection and recognition (ATD/ATR) algorithms. Since more processing power may be required, the analysis may take place within the cluster (sensors and gateway).

After analysis, an alarm and all target information would be sent to the command post. The information would be passed to the users as target information, not just phenomena and raw data. This should facilitate situational awareness and decision-making. The sensors should also have some mobile capability to orient themselves for better performance.

As for wireless communication, it should be resistant to detection, jamming and interception. This could be realized using spread spectrum technologies. In addition, the sensors should be able to establish a mesh or ad-hoc network and function collectively. Wireless transmissions could be routed around physical obstacles (mountains, trees, buildings, etc.) or from within closed compounds to reach the gateways, i.e. not limited by LOS. Routing should be transparent to the users, with due consideration for both energy and communication efficiencies. The network should also have “self-healing” capability. In the case where a defective sensor hinders network operation, the remaining sensors should be able to re-route automatically to re-establish the network. The sensors should have dynamic capability to respond to and track targets. For example, the sensors would be switched down to maintain the minimum surveillance sufficient to cover the AO. When targets are located, the sensors that are within range should be turned on automatically to gather information. When the targets move on, other sensors that come within range of the targets should be turned on accordingly. This scheme provides the best surveillance capability with minimum power consumption. Communication is short-range up to 500 m between sensors and gateways. The communication protocol could be proprietary. Between gateways and the command post is long-range communication up to 10 km. This protocol should be standardized to those of allied forces, NATO or UN forces for interoperability. As a result, each gateway will be equipped with two transceivers.

Other important aspects include system size, weight and battery life. UGSs clearly should be hand-portable (compact and lightweight) and have low power consumption for long mission life. A modular design could improve the overall versatility of the system.

Conclusions

In this study, various technologies applicable to UGS operation were selected, evaluated and implemented in a novel UGS prototype named AMIGO, which was then tested for system performance, operational usability and new mission concepts. AMIGO is equipped with different sensors and other electronics to detect various phenomena and to provide usable information. The sensors include a passive IR motion sensor to detect target movement and an acoustic sensor to detect sound generated by targets, and these two sensors trigger an IR imager to obtain and IR image of the target in either day or night conditions. This is an event-driven operation. An electronic compass determines the imager viewing azimuth and GPS provides the geo-position of the AMIGO unit. In mobile AMIGO units, GPS also provides real-time position tracking. A frequency-hopping spread spectrum transceiver is used to ensure low probability of detection and interception of digital communications. A laptop PC is used as a base station displaying all collected information through a graphic user interface. Aerial or satellite images with geo-referencing can be displayed with overlaid AMIGO positions for better visual and information presentation. Four AMIGO units were built, two of which have IR imagers. Each unit weighs 800 grams and measures 150 by 85 by 75 mm without batteries. Three different types of battery can be used according to mission type.

Table 3. Specifications of AMIGO system

	AMIGO WITH NO IR IMAGER			AMIGO WITH IR IMAGER		
Physical characteristics						
Dimensions (mm)		150 by 85 by 75			156 by 85 by 75	
Weight without battery (grams)		760			797	
Battery options (number required)	BR-C (2 units)	L123 (3 units)	LC3135A (2 units)	BR-C (2 units)	L123 (3 units)	LC3135A (2 units)
Total battery weight (grams)	82	48	760	82	48	760
Tested operation time (hrs) @ 100% duty cycle[1]	20	Not applicable	48	Not applicable	2.5	25
Estimated standby time (hrs)[2]	167	–	333	–	47	333
Sensors and electronics						
Passive motion sensor (Senses moving human up to 10 m)		Yes			Yes	
Acoustic sensor (Senses a running vehicle up to 20 m)		Yes			Yes	
Uncooled IR imager (160 by 120 pixels, 40^{o} FOV)		No			Yes	
GPS		Yes			Yes	
Electronic compass		Yes			Yes	
FHSS RF transceiver (2.4 GHz, IEEE 802.11, 0.1W RF)		Yes			Yes	
Maximum comlink distance						
Line of sight (LOS):						
- Remote on tripod	1.2 km					
- Remote on ground	650 m					
Partial LOS:						
- Remote on tripod	550 m					
- Remote on ground	360 m					
Non-LOS:						
- Remote on tripod	175 m					
- Remote on ground	150 m					
Imager performance[3]						
Human detection/recognition		Not applicable			220 m/135 m	
Vehicle detection/recognition					300 m/165 m	

[1] All components (GPS, IR camera, transceiver, etc.) running. [2] GPS, transceiver, CPU, camera in sleep mode. The average mission life is between the number of hours achievable in standby mode and the number achievable while running in 100% duty cycle. It is understood that the system is typically running in low duty cycle. [3] The range can be increased substantially by reducing the FOV.

Once fabricated, AMIGO was tested for basic performance. This was followed by trials in simulated surveillance operations. Trials included personnel and vehicle proximity detection (by motion or sound) and target image acquisition, multiple sensor imaging for target position estimation by GPS triangulation, entrance event counting, indoor surveillance, real-time GPS position tracking, and aerial surveillance using a radio-controlled model plane. No false triggers occurred in any of the tests. A detailed performance specification was generated after these tests. In summary, personnel movement and vehicle sound could be detected by PIR sensor (personnel) and acoustic sensor (vehicles) at up to 10 m and 20 m, respectively. IR images were captured upon triggering by these two sensors. Depending on whether AMIGO has LOS, partial LOS or NLOS to the base station, RF transmission range is between 150 m and 1.2 km. In addition, target triangulation was demonstrated with target images obtained from two locations with a precision of 2 m. AMIGO real-time tracking on a land or air vehicle was also demonstrated. It was noted that the target detection and recognition range could be increased by using optics with a smaller FOV in the IR imager. As for battery life, AMIGO with no IR camera operated between two days (full duty cycle including the RF transceiver and GPS) and 14 days (standby all the time). AMIGO with IR imager operated for one day (full duty cycle including the imager, transceiver and GPS). It is safe to assume 15 seconds transmission time per message for AMIGO. AMIGO with no IR imager will allow 2 days × 24 hrs × 60 min × 60 sec / 15 sec per activation = 11,520 activations, while 5,760 activations are possible with IR imager. The overall specification is summarized in Table 3.

The following are some new functions and features demonstrated using the AMIGO prototype UGS: (1) In self-trigger mode, one or more remote units can be self-triggered upon proximity disturbance (personnel, vehicles) and take target IR images. (2) In trigger-other-unit mode, multiple remote units can be deployed over an area to detect intrusions and enemy movement and trigger one or more imaging remote units located at strategic positions (treetops, roofs, etc.) for wider coverage. (3) With images of a target taken from two locations, its GPS position can be determined automatically by triangulation. (4) The real-time GPS tracking mode converts a manned or unmanned vehicle into a continuous GPS-tracking surveillance vehicle. (5) The situation inside a closed compound could be monitored from a base station. (6) FHSS technology provides LPD/LPI communication in a UGS system. (7) Mobile capability was integrated into the design.

Based on the specifications, capabilities and documented peformance, the AMIGO prototype is more capable in many areas than the COTS Classic 2000 UGS system. Target recognition is significantly improved with the addition of an IR imager. Target and AMIGO position tracking in real time is also made available with the addition of GPS electronics. All information is displayed to users through a graphic interface. The battery life is longer in the AMIGO with and without IR imager. With the test results in the simulated scenarios, it is clear that many surveillance options could be performed with this UGS configuration.

Future work

In subsequent UGS research and development, the modular approach will be considered instead of the current “all-in-a-box” design; a prototype was designed and is being built (Figure 41). In the next generation, the unit will be designed in three main “LEGO-type” modules: imager (expensive IR or low-cost visible), main body with basic low-cost sensors and electronics, and mobile platform. As a result, the sensor capabilities can be tailored to mission requirements. Moreover, a reliable wireless network is indispensable. This challenge is heightened by the limitation of radio transmission power available at each node for acceptable mission life and sensor weight. Since it is impossible to accurately predict the effects of terrain, weather and surrounding structures on wireless communications in the area of operation, a smarter network is desirable. The advanced development of ad-hoc networking will produce a more versatile multi-node wireless network. For example, Crossbow Technologies Inc. has developed wireless transceivers that can create an ad-hoc network of up to 1000 nodes. These low-power transceivers (mote RF link) adopt the IEEE 802.14.5 ZigBee wireless interface standard and run the proprietary mesh networking stack software modules. They could be used within a cluster. Their communication range is up to 100 m. A more powerful IEEE 802.11b/g could be used between gateways for long-range communications. These mesh-network-ready transceivers will be integrated into the next UGS system.

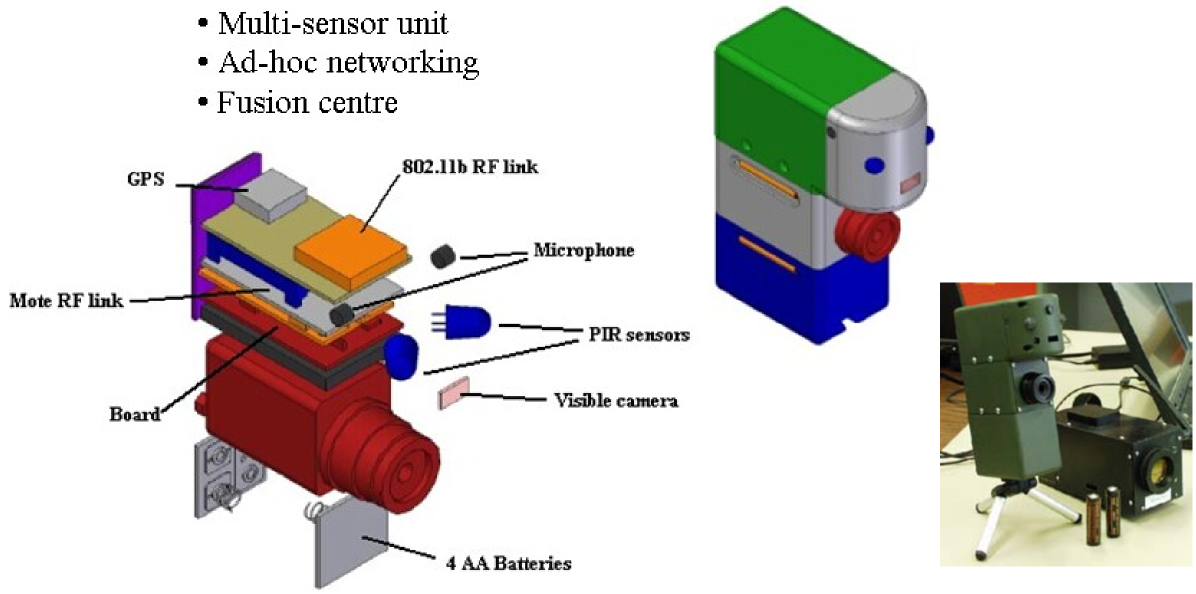


Figure 41. Concept of modular architecture and a prototype unit

In order to include data processing capabilities for an intelligent UGS system, acoustic signature analysis for target azimuth and classification from the project Acoustic Small Arms Detection at DRDC could be integrated into future systems. In addition, UGS development will explore the feasibility of implementing automatic target detection and recognition (ATD/ATR) and tracking capabilities in UGS systems. There are two on-going projects that are pertinent. The first involves DRDC and AND Corporation in the development of a holographic neural intelligence algorithm called HNeT to identify targets. The second involves DRDC and BCI in the development of a small filter called Small Object Identification Filter (SOIF) to detect and track small targets. It may be possible to use one of these capabilities or both together to analyze small to medium-sized images and to house them in a compact system, either sensors or gateways. The user would only be notified with target information upon confirmation and recognition by the cluster. This would provide high-value target information to a command post.

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List of abbreviations

AMIGO	Autonomous Microsystems for Ground Observation
AO	Area of Operations
BGA	Ball Grid Array
CPLD	Complex Programming Logic Device
CPU	Central Processing Unit
CF	Canadian Forces
CFB	Canadian Forces Base
COTS	Commercial Off-The-Shelf
CSTA	Combat Surveillance and Target Acquisition
DC/DC	Direct Current to Direct Current
DOA	Direction of Arrival
EEPROM	Electrically Erasable Programmable Read Only Memory
FOV	Field of View
FHSS	Frequency Hopping Spread Spectrum
GIS	Geographic Information System
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
INSENS	INtrusion-tolerant SEnsor NetworkS
IR	Infrared
LAN	Local Area Network
LOS	Line of Sight
LPD	Low Probability of Detection
LPI	Low Probability of Interception
MCI	Monitor and Control Interface
MIDS	Mini Intrusion Detection System
MIPS	Millions of Instructions Per Second
NTSC	National Television Standards Committee
PCB	Printed Circuit Board
PIR	Passive Infrared
RF	Radio Frequency
RGS	Remote Ground Sensor
REMBASS	Remotely Monitored Battlefield Sensor System
RISC	Reduced Instruction Set Computing

RMS	Root Mean Square
RTC	Real Time Clock
SDK	Standard Development Kits
SPI	Serial Programming Interface
SRAM	Static Random Access Memory
SST	Spread Spectrum Transceiver
STANO	Surveillance Target Acquisition Night Observation
TCP/IP	Transmission Control Protocol/Internet Protocol
UGS	Unattended Ground Sensor
UK	United Kingdom
USART	Universal Synchronous/Asynchronous Receiver/Transmitter
WBE	Work Breakdown Element

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The objectives of the project AMIGO (Autonomous MIcrosystems for Ground Observation) are to explore technologies applicable to unattended ground sensor (UGS) systems and to develop a proof-of-concept, next-generation, low-cost, compact UGS suite that can provide the CF with real-time situational awareness from remote locations. Four prototype AMIGO units were designed, built and tested at DRDC Valcartier. Each AMIGO unit was equipped with passive infrared (PIR) motion sensor, acoustic sensor, uncooled infrared (IR) imager (installed in two of the four), electronic compass, global positioning system (GPS), and spread spectrum wireless transceiver. The physical characteristics of AMIGO are 150 by 85 by 75 mm in size and ~800 grams in weight without batteries. Three types of battery can be used depending on mission life requirement, with battery life between 20 and 333 hours. With the PIR and acoustic sensors, AMIGO can detect a human-size moving target at a maximum standoff distance of 10 m and a vehicle target with engine running at a maximum standoff distance of 20 m. The IR imager allows detection and recognition of vehicle targets at 300 m and 165 m, and for human targets, at 220 m and 135 m, respectively. The AMIGO unit was configured for multipoint-to-point communication (several AMIGO units to one base station). IR images and other information are transmitted wirelessly to the base station upon triggering by PIR or acoustic sensor. The range of the reliable wireless link is between 150 m and 1.2 km depending on sensor location, communication line of sight and terrain altitude. In addition, field trials were conducted with AMIGO in various scenarios. These scenarios include personnel and vehicle intrusion detection (by motion or sound) and target imaging, determination of target GPS position by triangulation, real-time GPS tracking, entrance event counting, indoor surveillance, and aerial surveillance on a radio-controlled model plane. In these trials AMIGO performed effectively and detected targets according to the specifications. The results showed that this prototype could be used on basic surveillance missions.

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Unattended Ground Sensors, Remote Ground Sensors, Uncooled Infrared Imagers

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